AD 769 399

USE OF WARRANTIES FOR DEFENSE AVIONIC PROCUREMENT

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Arinc Research Corporation
Annapolis, Maryland

June 1973

AD-769399

RADC-TR-73-249
Final Technical Report
June 1973

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ARINC Research Corporation

Sponsored by
Defense Advanced Research Projects Agency
ARPA Order No. 2360

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Rome Air Development Center
Air Force Systems Command
Griffiss Air Force Base, New York

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USE OF WARRANTIES FOR DEFENSE AVIONIC PROCUREMENT

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Contractor: ARINC Research Corporation
Contract Number: F30602-73-C-0207
Effective Date of Contract: 5 March 1973
Contract Expiration Date: 14 May 1973
Amount of Contract: $28,000.00
Program Code Number: 3G10

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This research was supported by the Defense Advanced Research Projects Agency of the Department of Defense and was monitored by A.J. Feduccia, RADC (RBRS), GAFB, NY 13441 under Contract F30602-73-C-0207.

FOREWORD

This report has been prepared by ARINC Research Corp. 2551 Riva Road, Annapolis, MD 21401 under Contract F30602-73-C-0207, Job Order Number 23600201 and ARPA Order Number 2360. Research described covered the period 5 March 1973 to 14 June 1973.

ARINC Research wishes to acknowledge the excellent cooperation received from the selected airlines, equipment vendors, and military representatives during the course of the information survey (Appendix IV presents a list of personnel contacted). Mr. R. Shorey of DDR&E and Mr. A. Feduccia (RBRS) GAFB, NY were the contract monitors.

This report has been reviewed by the RADC Information Office (OI) and is releasable to the National Technical Information Service.

This technical report has been reviewed and is approved.

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ABSTRACT

The potential benefit of using warranty agreements as part of military avionics procurements was investigated. Interviews were conducted with airlines, vendors, and military agencies that had made use of warranties. A life-cycle cost model was formulated to permit comparisons between warranty and no-warranty procurements. The model makes it possible to compute the optimum warranty time period and the break-even cost to identify the minimum additional funds that may be spent on warranty coverage.

The major conclusion of the investigation is that a properly constituted and applied warranty can yield significant reliability and life-cycle cost benefits and that broader use of warranties is advisable.

SUMMARY

1. INTRODUCTION

The objective of the four-month study reported on herein was to investigate the potential benefits of using reliability-related warranty agreements as part of military avionics procurements. The approach taken was to interview airline and military activities and their suppliers who have made use of warranties in the past. The survey included six airlines, six vendors, and seven military agencies. The objectives of the interviews were twofold. First, it was desired to assemble information concerning the collective experience of the interviewees with warranties to determine if expanded military use should be considered. The second objective was to determine if sufficient data existed to establish a subsequent in-depth (Phase II) economic analysis of warranty use.

A life-cycle cost model was formulated that permits cost comparisons between warranty and no-warranty procurements. The model makes it possible to compute the optimum warranty time period and a break-even or "indifference" cost to identify the maximum additional funds that may be spent on warranties.

2. CONCLUSIONS

The major conclusion reached is that a properly constituted and applied warranty can yield significant reliability and life-cycle cost benefits and that broader use of warranties is advisable. Additional conclusions resulting from the study are summarized below (see Section VI for detailed discussion).

2.1 Warranty Use

Airlines make extensive use of warranty not only for avionics procurement but for a wide range of other commodities.

2.2 Reliability Incentive

There is no certain answer to the question of how much reliability incentive warranties provide for airline avionics. Most vendors feel that there is definitely an incentive, but it is difficult to separate it from the incentive produced by competition.

2.3 Reliability Growth

Since the military supplier will suffer expense for failure of warranted units, he is deeply interested in introducing design/production changes that will increase the MTBF and will do so if the cost of such introduction is lower than the savings in warranty-repair costs.

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2.4 Maintainability Incentive and Growth

The maintainability characteristics of the equipment will benefit from a warranty provision for the same reasons that warranty yields reliability benefits.

2.5 Minimal Initial-Support Investment

If the supplier is to provide repair services over the warranty period, savings in repair facilities and equipment, handbooks, training, and spare parts inventory will accrue.

2.6 Life-Cycle Cost Control

With a warranty provision that applies over a significant time period and with options for renewal, the military user can be much more confident in controlling costs for a significant number of life-cycle cost elements.

2.7 Contractor Benefits

If warranties benefitted only the user, there would be little likelihood of their acceptance by manufacturers. In pricing the warranty-cost increment, the contractor estimates all costs associated with the warranty clause, and to these he adds his normal profit factor, perhaps augmented by a risk factor dependent on the length of the warranty period. If the product exhibits better R/M than anticipated, contractor profits are increased. In addition, a warranty provision offers the contractor a long-term, stabilized work flow plus the opportunity to acquire in-depth knowledge of his product's performance in the use environment.

2.8 Economic and Military Manpower Impact

If warranties are applied on a large scale, a significant portion of the dollar expenditure for equipment maintenance will transfer directly to the civilian economy. In the same vein, extensive warranty use will tend to reduce greatly the requirements for military maintenance personnel. With the recent elimination of the draft, an approach that reduces the need for skilled military personnel offers attractive possibilities.

2.9 Design to Cost

It is believed that a warranty provision not only complements "design to cost" but provides, finally, a strong rationale for the low-bidder approach to source selection, since the purchase price plus the warranty increment would actually represent a significant portion of life-cycle costs over the warranty period.

2.10 Warranty Application

To achieve a more workable warranty, it is important that the agreement be established with as few exclusions as possible.

2.11 Warranty Cost

It is clear that the warranty provision costs the contractor additional funds, which are generally added to the initial purchase price. These costs typically may range from 4 to 10 percent of the initial acquisition price per year of coverage.

2.12 Warranty Acceptance

Military-equipment contractors will generally be willing to respond to procurements containing warranty provisions. However, they all stressed the importance of clearly specifying the use environment. Most contractors would be reluctant to permit military maintenance organizations to accomplish warranty repair for which the contractors are liable for reimbursement.

2.13 Warranty Application Problems

There are possible special considerations, problems, and disadvantages associated with warranty clauses in military procurement of avionic equipment. Highlights are presented below.

2.13.1 Disputes

Unless a warranty provision is very broad in coverage, the vendor may honestly believe that a warranty claim is not valid, and a possible dispute results. This situation will occur most frequently when the equipment fails because it is exposed to environmental stresses that exceed anticipated levels. User damage caused by mishandling, damage in transit, and questions involving warranty termination may also lead to disputes.

2.13.2 Warranty Administration

There is no question that administration of a contract with warranty provisions introduces additional administrative problems if for no other reason than that it represents a departure from current practice. Although shipping a warranted unit back to the vendor for repair should not involve any greater procedural difficulty than shipping a non-warranted unit back to a depot for repair, some special administrative actions will be required.

2.13.3 Warranty Procurement

Procurement with a warranty provision introduces complexities not normally encountered. A fixed price is being paid for future guaranteed services. This creates problems in funding, in legal questions, and in assessing the realism of the price and the value of the warranty.

2.13.4 Unverified Failures

The rate of unverified failures is quite large, both in military and commercial applications. The handling, shipping, and test costs that will be incurred by the military for such unverified failures sent back to the contractor can be significant.

2.13.5 Pipeline Time

An often expressed concern of contractor repair with warranty is the greater pipeline time such procedures will entail. When unit repair can be performed at the flight-line or organizational level, this may be true. However, for depot repair, we see no particular reason for any appreciable difference in pipeline times; and in some cases contractor repair can provide significant reductions. To reduce pipeline time, several contractual and procedural policies can be adopted.

2.13.6 Reduced Military Self-Sufficiency

There is no question that the military will suffer reduced self-sufficiency over the warranty period when contractor repair is the usual warranty procedure.

2.13.7 Data Requirements

Some of the current warranty programs in the military require fairly extensive data reporting and analysis procedures. This was partly due to the experimental pioneering nature of the long-term warranty provision that was involved. To meet data needs, service data products were augmented by contractor-supplied data and analysis.

2.13.8 Effects on Small Contractors

We believe that there is some element of truth to the statement that a long-term warranty provision may present possible risks to a small contractor that would discourage his entering the procurement competition. However, airline experience indicates that this effect is not of major significance.

2.13.9 Compliance Assurance

Employment of performance bonds to assure warranty compliance is considered contrary to the spirit of the basic objective of warranties -- i.e., to couple vendors to the reliability growth process.

3. RECOMMENDATIONS

A number of recommendations are offered in regard to the future use of warranties for military avionics procurement. These are discussed below.

3.1 Warranty Application

The expanded use of failure-free type warranty is recommended since it is the type most easily administered and is most compatible with existing supply and maintenance administration systems. MTBF, MTBUR, and cost-type guarantees shall be considered only if improvements can be made in current data and record-keeping procedures.

Warranty provisions should be applied only to fixed-price production and maintenance contracts.

3.2 Application Criteria

Criteria for selecting equipments that would be candidates for warranty coverage are enumerated as follows:

- The unit should be field-testable.
- Moderate to high initial support cost should be required.
- The unit should be readily transportable to permit returning to the vendor's plant.
- The unit should be generally self-contained and not highly dependent on outside units to perform major functions.
- The equipment maintenance concept and reliability characteristics should permit achieving readiness requirements in an economic manner.
- Specific knowledge concerning the unit application in terms of expected operating time and the use environment is necessary.
- The product must be sufficiently developed that reasonable estimates of the expected reliability and maintainability may be made.

3.3 Warranty Provisions

Warranty provisions for avionic systems should continue to exclude consequential damages. Warranty plans should be formulated to provide the fewest exclusions possible.

Unless the unit has a very low MTBF and high-cost transportation problems, it is best to have the vendor perform the repair at his plant. For the very-low-MTBF, complex units that would cause difficulty in shipment, vendors possibly can have personnel located at major Air Force centers.

Future warranty agreements should place constraints on the turnaround time the vendor must achieve on units returned for warranty repairs. The use of a consignment-spare penalty is suggested since such an arrangement will maintain adequate systems support to offset spares unavailability due to lagging turnaround time.

For warranty returns, the vendor should pay for shipping back to the user. Negotiations on who pays transportation charges to the vendor should be conducted for each application.

As a very general rule of thumb, the warranty period for a failure-free type warranty should be at least three years for new units. However, this figure may actually be increased or decreased if a detailed warranty cost analysis is performed to show that the optimum period is some other value. For older, proven systems, it is possible that this warranty period of three years may be reduced. Unless there is a great possibility of variation in operating hours, it is suggested that the warranty period be based on calendar time.

If the production run is not too extensive (one year), it is probably best to use a single warranty start time, such as an average production delivery date. Therefore, a single warranty end-date will be in force, rather than different warranty end-times for the units.

3.4 Warranty Procurement

On research and development projects, the government should state its intentions of incorporating warranty provisions in the production contract. In this manner, the developing activity will design the product with the thought of warranty profit through good R&M characteristics.

A cost analysis should be performed for each proposed warranty application. Such an analysis investigates the relative cost in warranty and non-warranty situations and examines the cost of varying warranty time periods.

Warranty costs should be priced separately so that appropriate warranty and life-cycle cost analyses can be performed. This will also permit an evaluation of a design-to-cost requirement.

In the procurement contract with warranty, options should be provided for warranty renewal. However, it is probably best to leave the terms of such renewal open for negotiations based on the results of the initial warranty period.

3.5 Warranty Development

A warranty administration guideline should be developed to provide instructions to procurement, supply, and maintenance personnel with standard procedures and guidelines for securing and administering warranty contracts. A further part of this effort would be the formation of a set of standard terms and definitions applicable to the various warranty plans.

Efforts should be made to standardize the marking of warranty items and packaging containers.

A training program should be considered for key procurement, supply, and maintenance personnel relative to the use of warranty procurements and administration.

Additional emphasis should be placed on the ability to provide in the field unambiguous go/no-go testing for warranty-covered items (non-warranty items would materially benefit from such an effort as well).

Service data systems and data-analysis products should be reviewed to determine how they can be modified to provide data products to support warranty administration. As an interim measure, warranty contracts should continue to require contractor-supplied data products to describe equipment performance.

DoD should promulgate a policy statement encouraging the expanded use of warranties. Final clarification should be provided in regard to warranty funding. The recommended course of action is that initial production systems be funded with production monies, but that warranties on subsequent replenishment buys and warranty renewals be funded with O&M funds.

A study should be initiated to review the current R&M production testing and documentation requirements when warranty provisions are in effect.

3.6 Future Study

This report constituted the completion of the Phase I effort directed toward an initial review of warranty usage in the airline community and in the military. As part of this effort, it was established that it is possible to determine the value of warranty on an economic basis. Chapter V of this report presents an initial effort towards evaluation of the costs associated with the failure-free type warranty plan. Although Phase I was a limited effort, it was found that some data are available to support this type of analysis. It is thus concluded that a Phase II effort would be of value in providing a more in-depth analysis of alternate warranty plans, including a validation through the application of the models to selected equipment development programs.

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SECTION I

INTRODUCTION

Support of today's military avionic systems is beset with the problem of rising costs in the face of budget constraints. There is an urgent need to reduce support costs to levels that are consistent with funding limitations. One of the major factors associated with support cost is system reliability. It is apparent that the more frequently an item fails, the greater the need for labor and materials. Thus efforts to improve system reliability will yield the twofold benefit of reducing support cost and improving system availability.

Past efforts to improve system reliability have been directed toward comprehensive reliability programs requiring parts screening, predictions, and demonstration tests. These efforts have been partly successful, but they have not produced the desired result.

It has been reported that the airlines are achieving better reliability than the military in several selected areas, using avionics similar to military systems and in related environments.[1] A review of their procurement practices shows that the airlines buy off-the-shelf systems in a competitive market. In addition, most systems are purchased with one or more warranty provisions that provide protection against system failures. Although it has not been clearly established how warranties contribute to improved avionics reliability, it was considered worthwhile to investigate further the use of warranties and their attendant benefits. This study was therefore undertaken to gain further insight into the contribution of warranties in avionics procurement.

The study is to be accomplished in two phases. Phase I, reported on herein, was directed toward determining the opinions of selected airlines and their vendors on the value of their warranty provisions and establishing whether data were available to provide a quantitative base for the airline position. Although this initial effort was primarily qualitative, an effort was made to acquire such supporting data. Several suppliers of military avionics were also interviewed. The results of these interviews were analyzed, together with the data acquired, (1) to make a preliminary appraisal of the use of warranties for military avionics and (2) to establish the existence of more detailed data. A cost model reflecting warranty parameters was developed for use as an aid in the decision process regarding use of warranties.

If it is concluded from a review of the Phase I study results that warranties are beneficial and data are available, a Phase II study will be initiated to investigate the situation in greater depth. Specifically, this study will seek to quantify the qualitative conclusions resulting from

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[1] P. Klass, *Aviation Week and Space Technology*, 13 February 1967.

Phase I, i.e., provide quantitative answers to the basic questions posed. These answers will constitute the basis for a DoD policy on the use of warranties for the purchase of avionic systems.

This report presents the results of the Phase I interviews, together with recommendations regarding use of warranties for military avionics.

SECTION II

IMPACT OF WARRANTIES ON LIFE-CYCLE COST

2.1 DEFINITIONS

The use of warranties has its roots in the commercial sector, for which the Uniform Sales Act is the source of warranty law principles. This act was drafted by the Commissioners of Uniform Law in 1906; since that time, a majority of the states have adopted it. Section 12 of this act defines an expressed warranty as "any affirmation of fact or any promise by the seller relating to the goods ... if the natural tendency of such an affirmation or promise is to induce the buyer to purchase the goods ... and if the buyer purchases the goods relying thereon." The major concern of this study is this area of expressed warranty. However, Section 14 of the act defines implied warranties and states in part: "where there is a contract to sell or a sale of goods by description, there is an implied warranty that the goods shall correspond with the description ... ."

The Uniform Sales Act has gradually been superseded by a Uniform Commercial Code (UCC). Since a 1963 decision (Noonan Construction Co. - ASBCA No. 8320) the Uniform Commercial Code has been applied in the interpretation of Government contracts on the basis that the UCC reflects the best in modern legal decision and discussion.

Questions frequently arise over the difference between *warranty* and *guaranty*. Black's Law Dictionary states:

> "*Guaranty* and *warranty* are derived from the same root, and are in fact etymologically the same word, the g of the Norman French being interchangeable with the English w. They are often used colloquially and in commercial transactions as having the same signification, as where a piece of machinery or the produce of an estate is "guarantied" for a term of years, "warranted" being the more appropriate term in such a case. Accumulator Co. v. Dubuque St. R. Co., Iowa, 64F, 70, 12 C.C.A. 37; Martinex v. Ernshaw, 36 Wkly. Notes Cas., Pa., 502. A distinction is also sometimes made in commercial usage by which the term "guaranty" is understood as a collateral warranty (often a conditional one) against some default or event in the future, while the term "warranty" is taken as meaning an absolute undertaking *in proesenti*, against the defect, or for the quantity or quality contemplated by the parties in the subject-matter of the contract. Sturges v. Bank of Circleville, 11 Ohio St. 169, 78 Am. Dec. 296. But in strict legal usage the two terms are widely distinguished in this -- that a warranty is an absolute undertaking or liability on the part of the warrantor, and the contract is void unless it is strictly and literally performed, while a guaranty is a promise, entirely collateral to the original contract, and not imposing any primary liability on the guarantor, but binding him to be answerable for the failure or default of another. Masons' Union L. Ins. Ass'n v. Brockman, 20 Ind. App. 206, 50 N.E. 493."

In view of the last point, *warranty* is the topic to be addressed in this discussion.

2.2 LIFE-CYCLE-COST IMPLICATIONS

Under the current policy for procuring military avionic systems, the producer's liability essentially ends with the delivery and acceptance of equipment. One possible approach to extend the producer's responsibility for the operational reliability of the delivered equipment is to incorporate warranty agreements in the procurement contract. For some time, the airlines have been using warranty provisions of numerous types in an effort to reduce their reliability risk and to spur competition for reliability improvement. The continued use of these provisions gives some evidence of their value and indicates acceptance by equipment suppliers.

It is desirable to explore some of the aspects of equipment development and deployment. It is generally well established that an equipment undergoes a reliability growth process from the time of its initial design until it finally reaches a state of maturity in the field deployment. Figure 1 illustrates two typical curves prepared from data obtained in a recent development program. Since such growth is a natural characteristic of equipment development, it is believed that warranty applications keep the vendor involved during this growth period to accelerate the rate of growth and to minimize the cost necessary to achieve it.

It should also be emphasized that higher MTBF can produce major cost reductions when viewed from the standpoint of life-cycle cost. Figure 2 depicts a case study performed several years ago for Navy transmitter equipment.[2] It will be observed that the life-cycle cost drops off markedly with increased MTBF and then gradually rises again as excessive demands are made on reliability development. Needless to say, most of today's equipment falls on the low side of the MTBF scale. Thus it is observed that although warranties may increase the initial purchase price of the equipment, they can indeed achieve higher reliability levels, and their cost can certainly be recovered in terms of the life-cycle cost of the equipment.

A final point to be made is that today's procurement practice, with the emphasis on low initial purchase price, causes vendors to supply the lowest reliability that will pass the procurement acceptance requirements. The vendor is economically driven to this position, his maximum profit being derived from such strategy. Profitability is based on total potential sales, including not only the initial purchase but follow-on spares, support equipment, and technical data. Several investigators have developed curves showing the relationship between the profitability and MTBF; they are generally of the form of the solid curve shown in Figure 3.[3] Ideally, the profit curve

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[2] N.J. Scarlett, Reliability Trade-offs during Concept Formulation -- Proceedings, Annual Reliability & Maintainability Symposium, 1968.

[3] Logistics Management Institute, *Methods of Acquiring and Maintaining Aircraft Engines*, Task 71-9, Washington, D.C., June 1972.

should be similar to the one sketched in, in which the contractor receives greater financial reward for improved reliability. These rewards can be paid for by reduced life-cycle cost of the supported product.

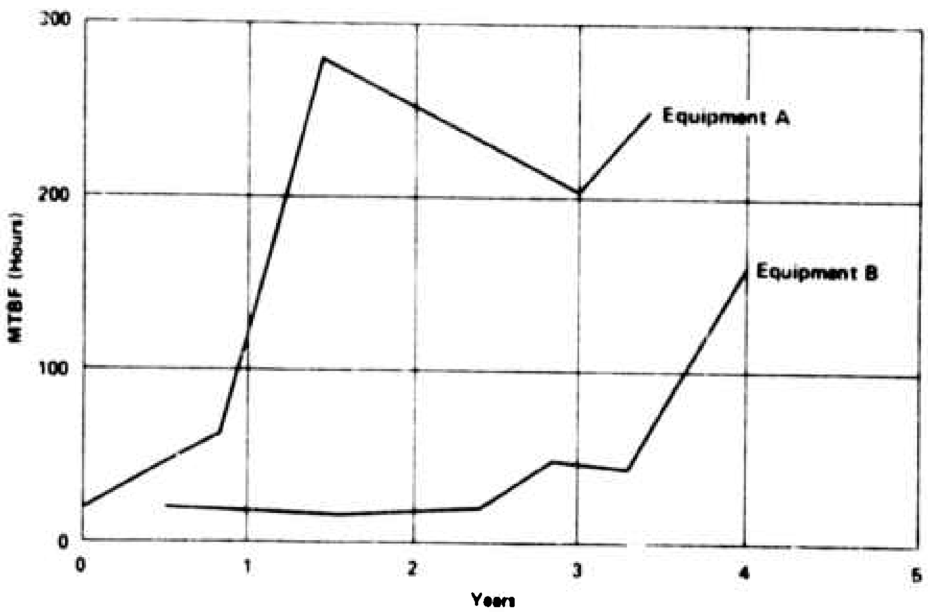

FIGURE 1

RELIABILITY GROWTH

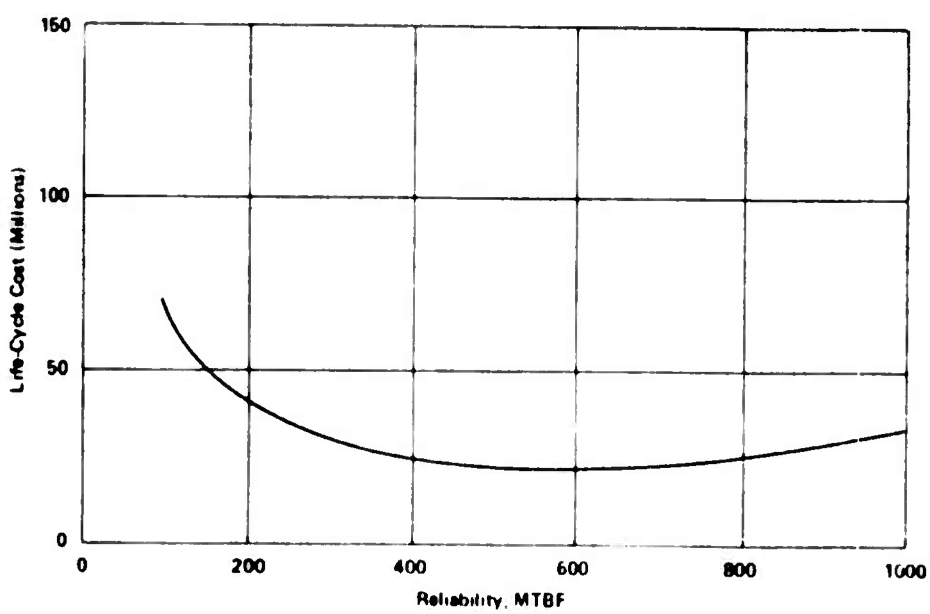

FIGURE 2

LIFE-CYCLE COST VERSUS RELIABILITY

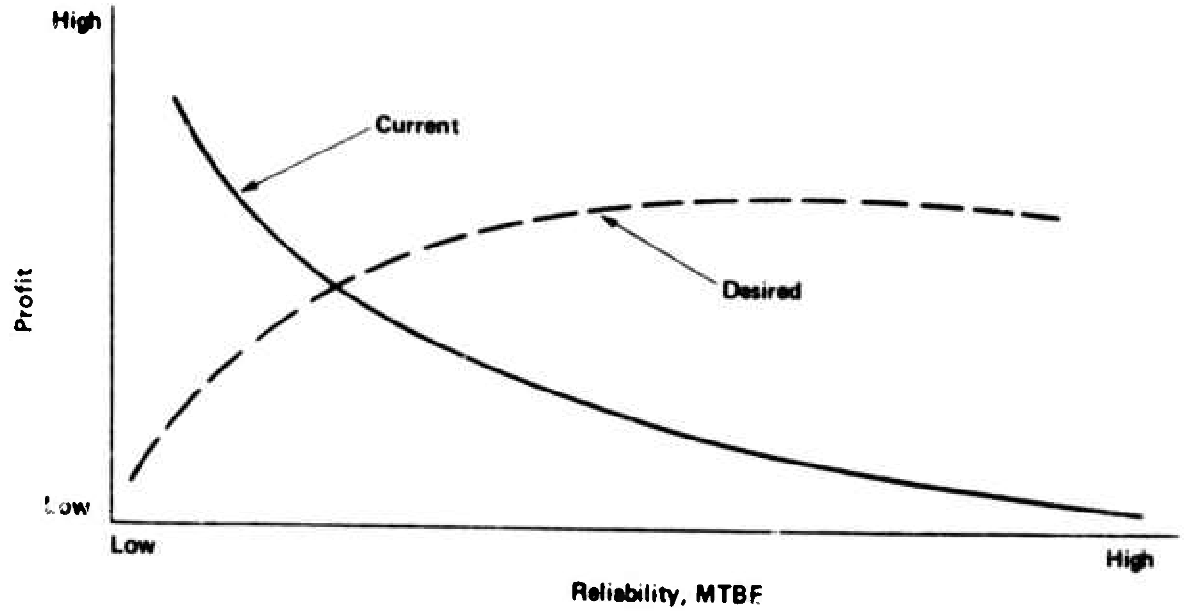

FIGURE 3

PROFIT VERSUS RELIABILITY

From a theoretical viewpoint the warranty concept appears logical. The purpose of the study was to review the practical application of warranties by both the airlines and the military so that better insight could be gained regarding their true utility.

2.3 *FAILURE-FREE* WARRANTY AND OTHER TERMINOLOGY

Unfortunately, warranty terminology is often confusing and has not reached any level of standardization. The term *failure-free warranty* is now commonly used in the military but cannot be considered an accurate descriptor of the basic warranty provisions involved or of the real intent. For this type of warranty, the contractor normally assumes responsibility for repairing warranted units that fail, the warranty period extending over a long period (minimum 1 year, typically 3 to 5 years). The extended period is required so that the contractor will have the profit/loss incentive involved with warranty-repair to invest the money required to improve reliability. Contract provisions are generally provided to minimize procurement and administrative complexities involved with introducing engineering changes for reliability improvement and to ensure that data feedback is provided by both parties.

Other terms that have been used to reflect basically the same type of warranty provision include *standard warranty, product warranty, long-term service warranty, contractor maintenance warranty,* and *full-life warranty.* Some fault can be found with the descriptiveness of each of these terms. Because *failure-free warranty* is most often used, we have chosen to continue using that term. At the risk of further complicating the terminology picture, we suggest considering the term *reliability warranty,* which, while not describing the warranty provisions involved, at least focuses on the major equipment characteristic of interest.

SECTION III

AIRLINE WARRANTY PRACTICE

3.1 THE AIRLINE PROCUREMENT ENVIRONMENT

It is appropriate to review the general environment under which airlines procure avionic equipment because of the influence such environment exerts on warranty practices. Where pertinent, contrasting military procurement procedures are noted.

It is clear that the major goal of an airline is to realize a satisfactory profit. It is also clear that to meet this goal avionic equipment must perform satisfactorily, have a low total life-cycle cost, and not jeopardize safety. If the term "military value" is substituted for "profit", this set of criteria for evaluating equipment is also quite applicable to the military.

A decisive element in airline avionic procurement practice is the AEEC (Airlines Electronic Engineering Committee). The AEEC, a standing committee of the Airlines Communications Administrative Council (ALCAC), is composed of 14 U.S. airline technical representatives, one representative from Canadian airlines, six from the European Airlines Electronics Committee, and one from general aviation. The committee has ten advisory members: ARINC (four); International Air Transport Association (one); Air Force (two); and the Air Transport Association of America (two). The committee is chaired by a representative of ARINC.

The primary function of the AEEC is to formulate form-fit-function types of standards for electronic equipment and systems. These standards are finalized through discussions between the airlines and potential manufacturers before the so-called ARINC Characteristics are published. The standards do not precisely define the contents of the "black box" but describe the signals that enter and leave the box and the electrical, mechanical, and environmental interfaces.

ARINC Characteristics produce the standardization that will assure the interchangeability in an aircraft of equipment produced by various manufacturers. The airline industry considers equipment interchangeability to be the greatest advantage offered by the development of ARINC Characteristics, for only through such standardization can a "buyer's market" for the airlines be achieved.

An ARINC Characteristic thus has a twofold purpose:[*]

(1) To indicate to prospective manufacturers of airline electronic equipment the opinion of the airline technical people, coordinated on an industry basis, concerning requisites of new equipment.

(2) To channel new equipment designs in a direction that can produce maximum possible standardization of physical and electrical characteristics without seriously hampering engineering initiative.

The AEEC has no authority. After a specification is issued, individual airlines can use it or not as they choose, and basically it is not a "procurement" specification in the military sense. The AEEC has learned over the years that this very lack of authority necessitates specifications that are soundly based on technical and economic facts; the alternative is, in effect, no standard at all. By and large, this process has been quite successful.

Once an ARINC Characteristic -- or specification -- has been issued, suppliers that have equipment meeting the requirements must obtain FAA certification. The FAA certification requirements, called Technical Standard Orders (TSO), are the equivalent of a military qualification test.

A unique aspect of these specification activities is that details of construction, cost, or reliability are never explicitly spelled out. These matters are left to be determined through contracting in a competitive market, but they are an important consideration during the preparation of the ARINC Characteristic. Major emphasis in the Characteristic, or specification, is placed, through the form-fit-function approach, on assuring that freedom of competition is preserved.

One good example of the value of interchangeability was a unique agreement under which one large airline purchased a radar system. If a specified MTBF value was not achieved within a specified time period, the airline had the option of returning all sets to the manufacturer, who would reimburse the airline for the purchase price. The airline observed that this agreement yielded one of the most successful programs for meeting prescribed reliability requirements.

The AEEC approach to avionic equipment specification and the simple fact that airline technical people "talk to each other" produces a very competitive situation. The single factor most often referenced by the many airline and vendor representatives interviewed by ARINC Research is the importance of manufacturer reputation and integrity.

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[*]More detailed technical description of ARINC Characteristics is presented in the report, *A Comparative Analysis of P3C Avionics Specifications and Similar Commercial Avionic Specifications*, W. Gahres, ARINC Research Corporation, Contract N00019-72-C-0486 (Naval Air Systems Command -- PMA), March 1973.

The airline market is a continuing one, and poor reliability of a vendor's product in one airline becomes known quickly to other airlines. The interchangeability of equipment assured by the specification of ARINC Characteristics obviates the necessity of "freezing in" design or reliability inadequacies.

There is also close communication between the airline and the vendor. Problems in performance, reliability, and support are quickly brought to the vendor's attention and, because of the competitive aspects (and, to be sure, because of the warranty provisions that usually exist), are generally acted upon in a positive manner. The engineering staffs of the larger airlines may even do some developmental work and recommend engineering changes to the vendors to reduce downtime. Because of competition and warranty provisions, vendors may then provide no-cost modification kits.

This competitive process is in sharp contrast to the military procurement situation, in which once a development is completed the design is essentially frozen and reliability competition practically ceases.

For military development contracts, competition certainly exists. With regard to production, the military has usually been obliged to contract with the original developer. Only when an equipment has been in the inventory for a long period will there be any likelihood of competition on production contracts. Airlines often utilize the new technology developed and proven by the military, so that a large percentage of avionic purchases involve essentially off-the-shelf equipment that a number of firms are capable of producing.

Finally, it appears to be universal that all airline equipment procurements have associated warranty provisions. Although some airline representatives (and more vendor representatives) have expressed feelings that warranty provisions have become too extensive, the trend has been to an increased scope in warranty provisions. Later subsections will present further details.

Table I summarizes the major elements of the airline avionic procurement environment and compares them with corresponding military practices.

3.2 AIRLINE USE ENVIRONMENT AND RELIABILITY COMPARISONS

The environmental levels and variations in the use environment are important factors to consider in developing appropriate reliability and associated warranty provisions. Airline avionic equipment operates in a relatively benign environment when compared with some extremes encountered in military usage. The competence and certainly the continuity of airline maintenance personnel are better than the military's.

On the other hand, average daily flying times of 10 hours or more for airline aircraft are not unusual, as compared with military averages that can be as low as 1 to 2 hours per day for fighter aircraft. This wide difference in usage is especially important when warranty periods are based on calendar time rather than operate time.

TABLE I

A COMPARISON OF
AVIONICS PROCUREMENT BY AIRLINES AND MILITARY SERVICES

Procurement Element	Airlines	Military Services
Technological Environment	Current technology satisfactory	Need to push the state-of-the-art in some areas
Specification Development	Done in open forum by AEEC, a group of users and manufacturers	More one-sided -- limited give-and-take sessions
Specification Format	Form-Fit-Function -- other characteristics not specified	Rigorous requirements on all characteristics (also, assurance procedures)
Specification Use	Individual users may or may not employ specification (voluntary)	Must be employed (mandatory)
Testing	Only through Tech. Standard Orders (TSO)	Rigorous acceptance tests
Contracts	Simple -- minimal paper work	Complex -- mountains of paper work
Warranties	Widely used	Seldom used
Competition	Exists at all times	Essentially ceases to exist after contract award
Information Feedback	Rapid, credible -- affects subsequent procurements	Not credible -- seldom a factor in reprocurement
Logistics	Standardization only to Form-Fit-Function	Standardization within black boxes -- minimizes number of types of spare parts

It should be noted that differences in observed reliability do exist among the airlines. One source reported a 7-to-1 difference in MTBFs for identical solid-state glide-slope receivers.[5] These types of disparities were confirmed by several airline and vendor personnel interviewed.

There are also differences attributable to aircraft type. One vendor claimed that because of cooling problems on one type of plane, the MTBF of his equipment was approximately half that of identical equipment aboard a comparable plane.

Despite known differences in airline operating environments and maintenance capabilities, vendors generally provide the same type of warranty to all customers and hope for a reasonable "averaging out" process. If one airline is experiencing abnormally high failure rates, a vendor will often provide on-site maintenance training and support to reduce this warranty cost.

Some data are summarized here to compare airline and military reliability for comparable avionic equipment and aircraft environment. For the military, data on the P-3C aircraft (similar to the Lockheed Electra) and the large reconnaissance and transport aircraft were used. For the airlines, the data apply to the current aircraft such as the Boeing 707, 747, DC-8, and DC-10. An attempt has been made to select equipments that are comparable in complexity at least to the extent that large differences in MTBF could not be attributed primarily to design and functional features.

The data are presented in Table II. It is immediately observable that airline avionics MTBF is significantly better than that of corresponding military equipment. The MTBF ratio of airlines to military ranges from approximately 1.5 to 1 to greater than 10 to 1.[6] These data support a widely held opinion that military avionics reliability is generally not as good as that encountered in comparable airline equipment and usage.

For the last three equipment classes in Table II, the comparisons are between essentially identical units. Excluding the DFA-70 receiver, the ratios of airline MTBF to military MTBF are 1.7:1, 1.8:1, and 3.3:1, which are comparatively much better than the ratios observed when the military is not using off-the-shelf commercial equipment. No explanation can be given at this time for the 8.4:1 ratio of the DFA-70 unit.

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[5] "New Data Yield Clues to Reliability", P. Klass, *Aviation Week*, 13 February 1967.

[6] Note that the greater than 10-to-1 ratio pertains to a comparison of a LORAN-A to a LORAN-C. The greater functional complexity of LORAN-C would account for some significant MTBF differences.

TABLE II

SOME COMPARISONS BETWEEN AIRLINE AND MILITARY AVIONICS RELIABILITY

Equipment	Source (M = Military)	Operating (O) or Flying (F) Hours	Number of Removals	Number of Failures	MTBR	MTBF
Weather Radar						
RDR-1F	Airline A	438,480(O)	1,307	390	335	1,124
RDR-1F	Airline C	NA(F)	NA	NA	555	1,157
AVQ-30	Airline B	186,810(O)	561	NA	333	666*
AN/APS-115	P3C (M)	19,450(O)	295	149	66	130
Inertial Navigation						
Carousel	Airline B	326,500(O)	925	NA	353	706*
LTN-51	Airline Composite	360,720(O)	NA	361	450*	999
AN-ASN-84	P3C (M)	35,900(O)	442	186	81	192
LORAN (A & C)						
345 & 700(A)	Airline B	182,460(O)	568	NA	322	644*
AN/APN-151(C)	RC-135(M)	9,600(O)	NA	94	51*	102
AN/APN-157(C)	C-141/HC-130H(M)	164,400(O)	NA	3,823	22*	43
HF Communications						
618 T-2	Airline B	228,400(O)	555	NA	412	824*
ARC-142	P3C (M)	28,520(O)	608	160	47	178
UHF/VHF Communications						
RTA-41A	Airline B	326,530(O)	591	NA	552	1,104*
ARC-143	P3C	37,430(O)	468	115	80	325
Automatic Direction Finder (Receiver)						
DFA-70	Airline Composite	647,270(F)	643	359	1,006	1,802
DFA-70	RC-135/WC-135(M)	30,150(F)	NA	141	107*	214
DFA-73	Airline Composite	38,500(F)	41	26	939	1,480
DFA-73	C-141/HC-130(M)	1,100,000(F)	NA	1,240	444*	887
Marker Beacon (Receiver)						
51Z-4	Airline Composite	570,300(F)	180	114	3,168	5,000
51Z-4	C-141(M)	506,670(F)	NA	184	1,376*	2,753
VOR Localizer (Receiver)						
WIL 806A	Airline Composite	NA(F)	NA	NA	570	1,000
WIL 806A	C-141(M)	506,670(F)	NA	1,654	153*	306

*Data not available. For gross comparison, estimate based on MTBF = 2 × MTBR.

The observed differences may be due to one or more of the following causes: procurement practices, operational environment, maintenance environment, equipment design and complexity, and reporting procedures. While it is not possible to quantify the degree to which these factors affect observed MTBF, the extensive airline use of warranty provisions in their avionics procurement contracts would certainly exert a positive influence on initial reliability achievement and on reliability growth.

3.3 TYPES OF WARRANTIES AND CONTRACTUAL PROVISIONS

3.3.1 Types of Warranties

The *World Airline Suppliers' Guide*, published by the Air Transport Association of America, sets forth four basic types of warranties used within the industry:

1. Standard Warranty (failure-free). This type of warranty applies to avionics as well as a range of other items and, in effect, warrants that all items will be free from defects in material, workmanship, and design; conforms to specifications; and will be suitable for the intended use. The warranty extends for a specified number of operating hours or calendar time or a combination of both. The vendor normally assumes responsibility for labor and material costs necessary to correct any failures occurring during the warranty period. Standard warranties, typically, have been for a one-year period, but recently this period has been extended up to three years for the newer aircraft systems.

2. Ultimate Life Warranty. This type of warranty applies to major structural components, such as wings, fuselage, and landing gear. The agreement warrants that such components will be free from defects for a stated number of flying hours. Protection beyond the normal failure-free warranty period is provided, and claims are generally adjusted on a pro-rated basis consistent with the amount of usage achieved from the warranted item.

3. Reliability Guarantee. The vendor is required to have his product achieve a stated mean time between failures. Such agreements generally recognize that the initial deployment will experience infant mortality and thus require that the MTBF be demonstrated after some initial period of operational time. The warranty typically runs until the warranted MTBF has been demonstrated for a stated number of consecutive months. If at any time the vendor's products fail to meet the specified MTBF, the vendor is required (1) to supply additional spare units to support the airline's operations until the required MTBF is achieved and (2) to provide technical assistance and/or modification kits and labor to achieve the warranted MTBF.

4. Maximum Parts Cost Guarantee. Agreements are established with the airline on a maximum materials cost per flying hour (or other measure of usage) for maintaining, modifying, repairing, and overhauling

selected items. Typical applications include aircraft tires and brakes. Reimbursement to the user is made either on a 100-percent or a pro-rated basis of the difference between the actual cost and the specified guaranteed value. Guarantees, typically, are for a period of ten years, commencing with the product's first use.

3.3.2 Warranty Provisions

The scope of the provisions contained in airline warranties has expanded over the last several years. Appendix I presents a warranty agreement currently being used. This particular agreement was selected because of its comprehensiveness. The individual clauses are believed to be typical, although many warranty agreements do not contain all such clauses or present them in the detail of this sample agreement. The highlights of the major provisions in this sample agreement are as follows:

- Period of Coverage. A warranty period of 36 months or 8,000 operating hours, whichever occurs first, applies for the standard warranty.
- Condition for Maintaining Coverage. The warranted item must be used as specified and not subjected to unauthorized modification.
- Consequential Damages. The seller is not responsible for consequential damages that may result from failure of the warranted device.
- Scope of Coverage. The seller agrees to repair or replace without charge any nonconforming item.
- Assignability. Warranty rights may be assigned to a third party in the event that items are sold or transferred.
- Shipping Costs. The buyer pays for shipping warranted items back to the seller for repair. Shipping costs for return to buyer are borne by the seller.
- No-Trouble-Found Reimbursement. In the event that a defect or failure cannot be confirmed, the buyer must bear the expense of shipment and cost of testing.
- Documentation Requirements. Data that must be submitted as part of a warranty claim are specified.
- On-Site Repair Authorization. If authorized by the seller, the buyer may accomplish the warranty repair using his facilities and invoice the seller for his labor and material subject to agreed-upon labor rates and other conditions. For some recent warranties, on-aircraft remove/replace labor costs are included.

Provisions applicable to a MTBF warranty are as follows:

- Specific Guarantees. A statement of the warranted parameters will be given (MTBF, materials cost, man-hours/flight hours, etc., will be annotated).

- Acceptance Conditions. A statement of tolerance and time period for compliance will be given.
- Seller's Data Requirements. The buyer will supply the seller with system failure data to permit collection of required parameters.
- Spares Requirements. The buyer will determine spares requirements based on the seller's MTBF guarantees.
- Consignment Spares. Additional spares will be supplied on a no-charge basis in the event the observed MTBF is less than the guaranteed value. The number of spares is calculated by the formula

$$n = NS \frac{G - A}{G}$$

  where

  n = number of additional spares

  NS = total number of spares purchased to date

  G = guaranteed MTBF

  A = achieved MTBF

- MTBF Calculation. MTBF measurements will be based on a monthly measure corresponding to a three-month moving average.
- Obligation Termination. The seller's obligation under the MTBF guarantee will terminate when the MTBF exceeds the specified value twelve consecutive months but no earlier than the 25th month after system introduction.
- Definition of Failure. Criteria are established that define which failures may be accepted in the MTBF calculation and which are to be classed as irrelevant or minor.

3.4 AIRLINE WARRANTY FEATURES AND EXPERIENCE

This section summarizes the features, experiences, and commentary concerning airline warranty practices as determined from the detailed interviews conducted with 27 key airline and airline-avionics vendor personnel. Six airlines are represented -- one regional carrier, two medium-sized national carriers, two large national carriers, and one large international airline. Six avionics vendors are also represented, ranging in size from small to large. In addition, some material from a literature search is presented.

Table III is a very condensed summary of airline avionics warranty practices with respect to a number of factors. More detailed information is presented in the following subsections.

TABLE III

SUMMARY OF AIRLINE
AVIONICS WARRANTY FAILURES

Feature	Description and Comments
Use of Warranties	Widespread. Trend is towards more comprehensive coverage.
Purpose of Warranty	Extend vendors' responsibility to include field performance.
Types of Warranty	Standard (FFW), MTBF, MTBUR, M cost guarantees.
Warranty Period	Standard, 3 years; others, up to 5 years.
Warranty Administration	Direct clerical cost to administer warranty claim, $15-$35 (burdened).
Airline vs Vendor Maintenance	Varies. Most large airlines do own maintenance. Reimbursed for labor at about $10 per hour and for replacement parts.
Turnaround Time	Generally ranges from 5 days to 30 days exclusive of shipping time. For most avionics, 2 to 3 weeks is typical. Until recently, no penalties have been associated with turnaround-time delays.
Lost Claims	Enough claims are lost to institute procedures to minimize the amount.
Unverified Failures	Ranges of 20% to 80% have been quoted for unverified failure occurrence. BITE equipment has not yet produced significant improvements. Cost of no-trouble-found tests ranges from $50 to $200, although could be much higher for very complex equipment.
Disputes	Major cause is interface problems. Generally settled through negotiation. Airframe manufacturer appealed to as last resort. Care in examining possible escape clauses before contract signing can minimize disputes.
Warranty Cost	Included in equipment purchase price but difficult to summarize. As a percentage of original purchase price, a range of 4% to 10% per year is fairly typical.

3.4.1 Use of Warranties

Warranty use in the airlines is widespread, and the trend appears to be towards more extensive and definitive coverage. A major extension of warranty coverage began with the introduction of the Boeing 747 aircraft, and this wider scope has been adopted by other major airframe manufacturers and vendors. Although verbal agreements and "implied warranty" have served well in the past, all airline personnel indicated that written precise warranty agreement is now a standard practice for almost all avionics procurement.

3.4.2 Purpose of Warranty

A number of opinions on the purpose of a warranty were expressed. Some typical examples are listed below (A = airline, V = vendor).

"Extend quality-control effectiveness" (A)

"Form of insurance" (A)

"Protection against catastrophic losses" (V)

"Part of company support" (V)

"Get reliable equipment" (A)

"Recover costs if something goes wrong" (A)

"Marketing tool" (V)

"Control ownership costs" (V)

"Provide customer time to build up maintenance capability" (A)

It is seen that no single major purpose is advanced for warranty. Stating that a warranty clause extends the manufacturer's responsibility to include field performance would probably be considered by most knowledgeable people as a reasonable overall purpose.

3.4.3 Types of Warranty

Most of the types of warranties listed in the Airlines World Buyers' Guides or shown in the sample agreement of Appendix I have been used by one or more airlines. The standard or failure-free warranty is most universal. Current practice is to include MTBF guarantees as well, although there is a trend towards replacing this with a MTBUR guarantee (mean time between unscheduled removals).

Some airlines have stated that they have data problems with the MTBF guarantee; others have had no problems. Most airlines that have some type of cost guarantee have admitted that currently they are very difficult to administer because of the data-tracking and accounting problems.

Other types of warranty agreements that are or have been used recently include: (a) dispatch reliability, (b) turnaround time, (c) turnaround time

in combination with MTBF, (d) guaranteed spares availability, (e) equipment return/cost reimbursement for failure to meet MTBF goal, and (f) maintainability guarantees.

In most recent aircraft purchases, the airframe manufacturer requires warranties from all avionics vendors, although specific terms may be negotiated individually with the airlines. Most airlines prefer dealing directly with the avionics vendor concerning warranty action and involving the airframe manufacturer only when disputes arise.

3.4.4 Warranty Administration

The administration of warranty claims by airlines varies. Some carriers have formal warranty claim departments under either purchasing or maintenance divisions. In others, the warranty claims are handled by procurement personnel who also have other duties.

It was not possible to obtain a substantial quantity of data on the cost of warranty administration. A summary of the minimal data collected pertaining to all aircraft products is presented as follows:

- The number of people in the warranty-administration departments for three large airlines averages eight, but all noted that other personnel (e.g., maintenance, purchasing, data processing) also spend some time on warranty-administration duties.
- The administration cost per warranty claim (burdened) was reduced by one carrier from $50 to $60 down to $15 by the introduction of more efficient clerical procedures. Another carrier noted that the clerical salary cost per claim averaged $16.

The forms used by the airlines for processing warranty claims vary. Currently, a committee composed of airline representatives under the auspices of the Air Transport Association is attempting to develop a standard form for airline processing of warranty claims. This form would apply when the airline performs the repair and is to be compensated by the vendor for labor and materials.

3.4.5 Warranty Period

Most current warranties for avionic equipment cover a three-year period for the standard or failure-free warranty. In some cases, where the equipment has proven itself, the period has been reduced (at some price saving to the airline). Where calendar and operating times are given, the ratio of 2,000 to 2,700 operating hours per calendar year seems fairly standard. In some cases, the warranty period starts with delivery; others account for shelf life before initial installation; and still others use an "average" delivery or installation time as the starting basis.

For MTBF, MTBUR, and cost-type guarantees, the period is usually five years, although it may be extended if requirements are not met. To account

for "infant mortality" problems, there may be a stated initial period over which the warranty is not in force, or the guarantee values are made less restrictive initially.

3.4.6 Airline vs. Vendor Maintenance

Most warranty agreements with airlines that have approved maintenance capability provide the airline the option of performing its own maintenance. Rates for labor-cost reimbursement are negotiated (currently, $10 per hour is often quoted), and the vendor supplies repair parts. Frequently, the agreement includes a stated maximum number of labor hours for repair at the module or unit level.

Most airlines prefer to do their own maintenance even though the negotiated labor rate generally will not recover all of the overhead expense. They feel that the savings in turnaround time and resultant reduced spares requirement provide a sufficient offset. For complex or new equipment, however, manufacturer repair on warranty items may be chosen initially until a maintenance capability is established. Also, there is a possibility of conflict with union agreements if all repairs are done by the vendor.

From the vendor viewpoint, a variety of opinions were expressed. Most vendors will allow airline maintenance, but they all noted that there is a wide variation in capability among the airlines. Vendors prefer to do repairs, at least on newer items, in order to observe directly which types of failures are occurring, to track failure patterns, and to perform failure analyses so that they can improve the product and thereby reduce warranty-repair costs. A smaller vendor did note, however, that if all airlines returned units under warranty, their repair facilities would be very much overburdened.

In many cases vendors will maintain representatives at, or periodically send them to airline maintenance centers to provide expertise and periodic training of maintenance personnel. The larger vendors have also established world-wide service centers to handle warranty claims.

3.4.7 Turnaround Time

The newest warranties include provision for guaranteed turnaround time (which may or may not include round-trip shipping time). The typical warranty provision involves the consignment of additional spares based on the equation

$$N = R(t - T)$$

where

N = number of spares to be consigned

R = 3-month moving average of quantity of units per day returned for warranty repair

t = average turnaround time (days, 3-month moving average)

T = guaranteed turnaround time

A large variation in actual turnaround times was expressed by both the airline and vendor interviewees, ranging from 5 days to 30 days (exclusive of shipping time). The five-day period was for a vendor who has established a rotable pool. A period of two weeks is probably a reasonable average that can be used for most avionic equipment.

3.4.8 Lost Claims

For various reasons, a number of valid warranty claims are not made. One representative of a very large airline believes that a total of seven to eight million dollars in warranty reimbursement claims was lost one year by his company. The most frequently cited reasons are record inadequacies; failure of line maintenance personnel to follow standard procedures; and the need for quick turnaround, occasionally dictating in-house repair for which a warranty compensation provision may not exist.

For general-aviation equipment, one vendor noted that only about 40 percent of warranty registrations are sent back and, of these, the percentage of warranty claims is much lower than the observed MTBF would indicate.

3.4.9 Unverified Failures

Both airlines and vendors noted that a great many removals are unverified failures. Ranges from 20 percent to 80 percent have been noted. An average figure of 40 percent is probably reasonable. One major reason cited for this relatively high rate is that FAA regulations require some type of action if a complaint is registered. Usually the easiest course of action on the flight line is remove and replace, especially when a plane full of passengers is involved.

It was also noted that the introduction of BITE (built-in test equipment) has not yet significantly improved the unverified rate and in some instances may have increased it (e.g., signal reflections off a hangar during a bank may activate an error indicator even though the unit is working perfectly). The BITE circuit may also experience some reliability problems, causing a false indication of unit failure. Current state-of-the-art improvements in BITE and relaxation of the design philosophy of testing everything may improve the effectiveness of BITE in the future.

There is no uniform practice concerning no-trouble-found test charges, but for a large number of items the vendor will bill the airline. A minimum charge of $50 appears to be standard, with a maximum of about $200, although charges as high as $750 for a complex intertial navigation system have occurred. The airline will generally also be charged for shipping costs. Specific actions have been taken by airlines to reduce these costs by better checkout procedures. In one case, an airline will receive credit for a no-trouble-found test charge if the unit fails again within 30 days.

3.4.10 Disputes

The widespread and increasing airline use of warranty provisions should not be interpreted to mean that disputes are rare. Interface problems were the most frequently cited cause of disputes, although this is probably more applicable to non-avionic equipment (e.g., the vendor claims that excessive engine vibration caused failure of a thrust chamber). Most disputes are negotiated directly between vendor and user. Again, the importance of manufacturer reputation and integrity in the competitive airline avionic market is worth noting. For cases in which no settlement can be reached, the airline will appeal to the airframe manufacturer when he has overall warranty responsibility.

The general impression gained from interviewing airline representatives was that disputes concerning warranty responsibility were more of a headache rather than a serious problem significantly reducing the value of warranty. A number of interviewees did mention that care has to be exercised in avoiding "escape clauses" in the contractual warranty provisions. The most frequently cited examples involved stipulations of operating and maintenance conditions for which the vendor could easily claim that the warranty was voided. Delays involving delivery and installation had also resulted in disputes concerning warranty-period coverage for individual units.

3.4.11 Warranty Cost

The cost increment due to a warranty provision is of considerable interest. There is no doubt that the price of avionic equipment includes estimated costs of future warranty repair and is therefore very much dependent on the anticipated MTBF performance. On the basis of a number of informed statements, a range of 4 percent to 10 percent per year of the basic unit purchase price is fairly representative. The lower percentages would apply to the simpler units with proven reliability. The higher percentages would apply to the more complex units, especially the newer ones that are still maturing.

The percentage rate cited generally applies to the standard type warranty, but it may include reliability guarantees and other forms as well. Because of the wide variety of equipment/warranty factors that are reflected in the percentages quoted, we caution against using them for decision-making purposes.

3.4.12 Miscellaneous Factors

Several other factors concerning airline use of warranty provisions in avionics procurement are summarized as follows:

- Small versus large vendors. No airline representative indicated any major difference in warranty experience between small and large vendors.
- Shipping costs. In many cases, the airline pays for one-way shipping costs on warranty returns, but this practice is not universal.

- Legal disputes. The number of legal problems resulting in court actions resulting from warranty provisions has been negligible for the airlines and vendors contacted.

- Performance bonds. No instance could be recalled in which a performance bond or similar contractual provision was used for avionics procurement.

3.5 THE VALUE OF THE AIRLINE AVIONICS WARRANTY

The widespread use of warranty clauses in avionics procurement and the trend to increased coverage must be considered as strong evidence of the value airlines place in warranty provisions. The airlines are no sold warranties; they seek them. No airline representative we interviewed would approve of purchasing equipment without at least a standard-type warranty.

Vendors accept the fact, perhaps reluctantly in some cases, that more than minimal warranties are now standard practice in airline avionics procurement. One vendor frankly stated that "warranties make us nervous". The reason for this feeling is clear. Although vendors try to include the estimated costs of warranty in the unit purchase price, a great deal of uncertainty exists, especially for the newer equipment.

To remain competitive, the vendor cannot make the price increment due to warranty too large. If the reliability of the product is good, the vendor may realize some additional profit because of the warranty. On the other hand, if some unanticipated reliability problem occurs, the vendor may incur a large warranty-repair cost. In addition, he may have to consign spares and introduce costly modifications if an MTBF guarantee is involved in the warranty clause. Therefore, the possible profit increment due to a warranty clause may be relatively small compared with the possible losses.

Many of the airlines people interviewed expressed the opinion that warranties are not designed to penalize a vendor. They believed that the profit/loss potential associated with warranties will motivate vendors to produce more reliable equipment and to provide timely support or modifications to improve equipment reliability performance. Warranties were considered by some as a form of insurance whereby the buyer recovers some of his excessive ownership costs if the product fails to meet reliability goals.

A great deal of money is involved in warranty claims. For three large airlines, the following statistics were obtained:

- Airline A recovered nearly $50,000,000 in warranty claims over a three-year period, exclusive of claims concerning serious engine problems, which have now been corrected.

- Airline B recovered a total of $14,500,000 in warranty claims over a two-year period (1971-1972).

- Airline C recovered a total of $11,000,000 in warranty claims for 1972 (conservatively estimated).

Information obtained from two of these sources indicates that 30 to 40 percent of these dollar values represent warranty claims for avionic equipment. The MTBF/spares-consignment provision can also involve a great deal of money. In one instance, a manufacturer had to consign 20 spares costing $100,000 each because of MTBF problems. A number of modifications to improve reliability were introduced by the manufacturer, resulting in an approximate doubling of MTBF.

Some differences were noted in the warranty philosophy of airline procurement personnel as contrasted with engineering personnel. The procurement personnel tend to place greater reliance in the warranty provisions and feel that a complete, detailed warranty clause could be a good basis for selecting a vendor. The engineering personnel, however, tend to place less reliance on the warranty specifics and more on technical reliability factors and manufacturers' reputations.

As an example of the latter, for an avionics item, one large airline did not select a vendor who proposed the lowest price (among seven bidders), a guaranteed high MTBF, the second lowest man-hours per operating hour, the lowest material cost per operating hour, and the best dispatch reliability. The engineering manager who discussed this case with us simply stated that this vendor had no known experience with this particular type of product and that he would be "scared" to commit the airline even with a warranty clause.

As discussed earlier in this section, warranties represent just one factor in the airline procurement environment that tends to yield reliability and life-cycle-cost values much more favorable than those of comparable military applications. Although it is not possible to quantify precisely the impact of warranty provisions, there is no question that the airline community has had a very satisfactory experience and intends to increase its reliance on warranty for more inclusive reliability and cost control.

SECTION IV

MILITARY WARRANTY INVESTIGATIONS

4.1 INTRODUCTION

The regulations regarding the use of warranties are covered in the Armed Services Procurement Regulation (ASPR), Paragraph 1.324. Within this provision, a general functional description of a warranty is provided by:

> "A warranty clause gives the government a contractual right to assert claims regarding the deficiency of supplies or services furnished, notwithstanding any other contractual provisions pertaining to acceptance by the government. Such a clause allows the government additional time after acceptance in which to assert a right to correction of the deficiencies or defects, reperformance, and equitable adjustment in the contract price or other remedies ... ."

Traditionally, this clause has been used in the context of correcting latent defects of materials supplied. Recently, however, the concept of warranty has been expanded to provide a much longer-term relationship with the contractor to achieve desired performance characteristics. Regarding the scope of a warranty, ASPR Paragraph 1-324.5 states:

> "The terms and conditions of the warranty clause vary with the circumstances of the procurement. The clause must state the duration of the warranty. The clause may either provide that the contractor will be liable for defects or nonconformance to the contract requirements existing at the time of delivery, or provide that he will be liable for such defects or nonconformance which developed prior to expiration of the specified period of time or before the occurrence of a specified event."

Subparagraph C states:

> "Where the government specifies the design of the item and its precise measurements, tolerances, materials, tests, or inspection requirements, the contractor's liability for defects or nonconformance should usually be limited to those in existence at the time of delivery."

It thus appears that the use of warranties is most clearly applicable to those situations in which the requirements are spelled out in general terms for the item rather than consisting of specific design details.

It is important to note that the warranty coverage is applicable only to correcting deficiencies found in the item procured and does not extend

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to consequential damages. Because of the possible magnitude of such damages, it has been considered by many sources to be within the government's best interest to act as a self-insurer for this area of liability for complex, high-value, or hazardous items such as aircraft, ships, missiles, and other military systems or components or spare parts.[7]

Warranty claims that cannot be resolved through the designated contract administrator would require resolution through the disputes clause. ASPR 7-103.12 provides in part:

> "Except as otherwise provided in this contract, any dispute concerning a question of fact arising under this contract which is not disposed of by agreement shall be decided by the Contracting Officer, who shall reduce his decision to writing and mail or otherwise furnish a copy thereof to the Contractor. The decision of the Contracting Officer shall be final and conclusive unless, within 30 days from the date of receipt of such copy, the Contractor mails or otherwise furnishes to the Contracting Officer a written appeal addressed to the Secretary. The decision of the Secretary or his duly authorized representative for the determination of such appeals shall be final and conclusive unless determined by a court of competent jurisdiction to have been fraudulent, or capricious, or arbitrary, or so grossly erroneous as necessarily to imply bad faith, or not supported by substantial evidence. In connection with any appeal proceeding under this clause, the Contractor shall be afforded an opportunity to be heard and to offer evidence in support of his appeal. Pending final decision of a dispute hereunder, the Contractor shall proceed diligently with the performance of the contract and in accordance with the Contracting Officer's decision ..."

Although this process can entail a lengthy resolution process, the contractor does have recourse to questions of fact regarding warranty claims. Ideally, the definition of warranty coverage should be sufficiently definite and broad in coverage to minimize the need for such action.

Warranties are typically concerned with the product's ability to meet prescribed performance characteristics such as reliability. A number of plans have been considered for warrantying reliability characteristics, but as yet no precise standards or commonality of terms exist to describe the various plans. Hughes Aircraft in their study of warranty outlined the following plans:[8]

a. Full-life guarantee plan - allows any number of failures consistent with Reliability, Maintainability, and Availability requirements of the operating Commands during the equipment life time, with the manufacturer responsible for repair and test of each item. (This type plan is also known as failure-free warranty; see Section II.)

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[7] DoD Working Group on Contract Warranties, June 1969.

[8] Airborne Electronic Equipment Lifetime Guarantee, Hughes Aircraft Company, RADC TR 69-363, November 1969.

b. Maximum failure-rate guarantee plan - allows a certain number of failures, per unit time, above which the manufacturer becomes liable.

c. Failure-free guarantee plan - does not allow any failures, with the manufacturer guaranteeing the equipment to be failure-free for an extended period, subject to heavy penalties.

d. Other - Used to denote an ASPR type of guarantee plan. In such a plan only qualitative correction-of-deficiency statements are made.

In addition to reliability guarantees, it is possible that warranties could be established for other utility indices such as support cost per landing, maintenance material cost per operational hour, or total life-cycle cost for some stated operational period.

4.2 MILITARY WARRANTY EXPERIENCE

4.2.1 Naval Aviation Supply Office

The Naval Aviation Supply Office placed a contract with Lear Siegler, Instrument Division, for the repair and refurbishment of 800 2171P gyros. The gyros are used in the A-4 and F-4 aircraft. The warranty provided that failures occurring during the coverage period of 1,500 hours or five years (whichever came first) would be repaired on a fixed-price basis. The fixed price was determined from the number of failures that would occur during the 1,500 hours of operation and the contractor's cost to perform a repair. The number of failures was derived from the previously observed field MTBF, modified to achieve a 30-percent improvement in reliability. The base MTBF was 400, which when increased by 30 percent would produce a 520-hour value. The 30-percent improvement was to be derived from (1) incorporation of existing modifications, (2) implementation of additional reliability improvements, and (3) improved overhaul processes.

The contract provided that all units returned to Lear Siegler, except units with broken seals or obvious damage, would be repaired and tested by Lear Siegler within the contract fixed price. Warranty exclusions were to be determined by the resident Government quality-control representative. The contract also provided that *no* additional charges would be made for units that were subsequently found to be good.

This program was implemented in 1968, at which time, as noted, the field MTBF was observed to be almost 400 hours; at the midyear point it had dropped to about 380 hours. The contractor intensified his actions to improve reliability and, as a result, a value of 523 hours was reported in April 1972.[9] Typical no-cost changes made to achieve these improvements included improved solder seals and the addition of an inner-race bearing nut to reduce trunnion wear. Other additional charges have been made, and others are being tested and evaluated.

[9] Lear Siegler, Technical and Contract Coordination Meeting Report, 22 June 1972.

The gyro field reliability performance is monitored through the use of 3M data plus data generated by Lear Siegler from monitoring its in-house repair activities. From these data, Lear Siegler has developed data-processing programs that develop warranty program history by equipment serial number plus a variety of summary reports related to configuration data, failure-mode distribution, and equipment-status statistics.

To date, approximately 2,000 units have been returned for repair. Of these, all but two have been repaired under the warranty. Both units were damaged to a point where repair was totally uneconomical. The Lear Siegler contract requires that units that are returned for warranty repair but are later found to have no defect are processed at no additional charge. Experience has shown the no-trouble-found rate to be 16 to 17 percent of total returned gyros.

Failed units are returned to Lear Siegler from either east coast or west coast Navy supply centers. Average transit time ranged from 53 to 69 days (removal to receipt). The average ship-to-install time was 87 to 109 days. Overhaul facility turnaround time ranged from 67 to 89 days. The warranty contract required that turnaround be accomplished within 45 days. Although no explicit penalty was called out in the contract, it was mutually agreed that the difference in actual turnaround time versus that guaranteed would be added to or subtracted from the warranty period.

An added benefit derived from the study was the performance of approximately 50,000 hours of laboratory reliability testing by Lear Siegler as part of their reliability-improvement efforts. Additionally, approximately 3,700 hours of field reliability testing of design-improved operational units was completed.

One major problem encountered in establishing the contract concerned the securing of proper funding authority. Since the program was related to maintenance, it was clear that O&M funds were appropriate. However, the warranty contract was a multi-year agreement, and O&M monies may be allocated on an annual basis only. Authority was finally received to fund the program incrementally on an annual basis.

Overall, both the Navy and Lear Siegler are satisfied with the program. Lear Siegler has indicated that the project has been profitable and highly useful since it provides direct feedback to them concerning the field performance of their products. Although definitive studies have not been made, Navy personnel believe that the Lear Siegler units have higher reliability than similar units processed through normal Naval repair facilities. Although no firm data are available, a 20-percent saving in repair costs and fleet maintenance costs has been estimated. Considering the cost of repair only, it is estimated to be $1,150 under the Lear Siegler program, as compared with $1,400 to $1,500 for repair at Naval facilities.

4.2.2 NAVAIR

NAVAIR has procured two systems using warranties -- the Radio Altimeter AN/APN-194 and an Omega receiver, AN/ARN-99(V-1). The highlights of these procurements are described in the following subsections.

4.2.2.1 Radio Altimeter

A procurement contract was awarded to Honeywell for a quantity of AN/APN-194 Radio Altimeters as replacements for the AN/APN-141. The contract includes a service warranty providing coverage of 1500 hours or two years, whichever comes first. The award price is $4,900 per unit, including warranty. The AN/APN-141 was priced previously at approximately $4,100. The contract also requires the contractor to repair or turn around all returned units within 45 days. Failure to do so results in a penalty of 0.5 percent per day of the acquisition price. An option for additional warranty coverage was provided at an annual rate of seven per cent of the original purchase price.

The AN/ARN-194 procurement made use of the normal specifications, including reliability and maintainability demonstrations, as well as standard configuration-control procedures.

Past experience with the AN/APN-141 indicated that it had an MTBF of about 40 to 50 hours. Experience to date on the initial production quantity of 24 units revealed a verified MTBF of approximately 700 hours. This was achieved in part through the implementation of several no-cost reliability ECPs by the contractor.

4.2.2.2 Omega Receiver

A contract was placed with Nortronics for procurement of the AN/ARN 99(V-1) Omega Receiver. The contract contains a two-year warranty clause. The maintenance concept for this unit is to employ built-in test to identify a failed module and to ship the failed unit back to the manufacturer for service.

The principal warranty provisions used for the Omega Receiver are as follows:

"Warranty - The Contractor warrants that at the time of acceptance all supplies furnished under this contract will be free from defects in material and workmanship and will conform with the specifications and all other requirements of this contract and that for two (2) years after acceptance all failures in supplies shall be repaired in accordance with the remedies set forth in this clause: provided, however, that with respect to Government-furnished property, the Contractor's warranty shall extend only to its proper installation, unless the contractor performs some modification or other work on such property, in which case the Contractor's warranty shall extend to such modification or other work."

"Right to Corrective or Replacement Action - In the event of a breach of Contractor's warranty or any failure in the supplies as noted in paragraph above, the Government may, at no increase in contract price, (1) require the Contractor, at the original point of delivery or at the Contractor's plant, to repair or replace, at the Contractor's

election, defective or nonconforming supplies, or (2) require the Contractor to furnish at the Contractor's plant such materials or parts and installation instructions as may be required to successfully accomplish the required correction. The Contractor shall also prepare and furnish to the Government data and reports applicable to any correction required under this clause (including revision and updating of all affected data called for under this contract) at no increase in the contract price. When supplies are returned to the Contractor, the Contractor shall bear the transportation costs from the original point of delivery to the Contractor's plant and return to the original point of delivery."

"Right to Equitable Adjustment - If the Government does not require correction or replacement of defective or nonconforming supplies or the Contractor is not obligated to correct or replace by reason of paragraph below, the Government shall be entitled to a reduction in the price of such supplies which is equitable under the circumstances."

Additionally, the contractor is required to correct or replace any item returned for warranty within 60 days of the date of return. In the event that action is not accomplished, the contract provisions provide for liquidated damages at the rate of 0.5 percent per day, not to exceed 25 percent of the unit cost.

No information is currently available to evaluate the success of this program.

4.2.2.3 USAF Aeronautical Systems Division

In 1966, The F-111 Aircraft System Project Office and the ASD Deputy for Subsystems, Compass and Reference System Section, initiated an effort to determine the best plan for additional procurement of the auxiliary heading and altitude reference system for the F/FB-111 aircraft. Previously, the reference system had been secured from General Electric on a sole-source negotiated-procurement basis. As part of the planning effort, it was decided to go to a competitive basis and to include a long-term service warranty provision.

An RFP was issued to 25 contractors; two responses were received -- G.E. and Lear Siegler. The resultant contract was awarded to Lear Siegler for 126 units, with delivery to be started in May 1971 and completed in May 1972 (Contract No. F33657-69-C00662). The warranty provision called for 3,000 hours or five years of use.

Through the competitive procurement, an acquisition-cost reduction of 37 percent was achieved on the total system (gyro, amplifier, and controller), or $9,550 per system, versus an average of $14,969 for previous procurement. The cost of the gyro was $6,040 per unit plus $2,200 for the five-year warranty. The warranty cost in terms of the gyro acquisition cost was 7.3 percent per year.

Cost of repair of the G.E. gyro under contract to G.E. was $1,622 for each repair. The Air Force depot cost to repair was estimated to be $1,275, eventually reducing to $978. Using these rates, J. L. Higgins showed that the hourly cost to operate the LSI unit was $2.75, compared with $3.03 for the G.E. unit with AF depot repair and $3.99 with G.E. factory repair.[10]

Failed gyros are sent to Lear Siegler via McClellan Air Force Base and from General Dynamics, the F-111 contractor, who is also installing the units in new aircraft.

To monitor the gyro performance, Lear Siegler makes use of AFM 66-1 and the Data System Automation Program Number D057 in association with their in-house data derived from monitoring their repair operations to monitor the reference system's performance. In addition, each gyro has its own time meter.

The unit is receiving approximately 26 flying hours per month and is incurring approximately 1.5 times that amount in ground time. It has been reported that Lear Siegler has incorporated two no-cost Class 2 changes in the gyro to date.

No specific operational results have been reported to date. The procurement section at Headquarters AFSC is preparing a cost-comparison study of the G.E. and Lear Siegler units. It is expected that results of this analysis will be available in July or August 1973.

4.2.2.4 USAF Electronics Systems Command

The Electronics Systems Command has under development a solid-state TACAN system scheduled to be the future standard replacement system for the current tube-type systems. It is designated the AN/ARN-106 (formerly ARN-XXX), and the development effort is directed toward achieving a design-to-cost value of $10,000 per unit and a 1,000-hour MTBF. Competitive development contracts have been let to Collins Radio and General Dynamics.

As part of the development proposal submitted, the competing contractors were asked to provide estimates for warranty coverage for an initial 24-month period plus annual options for three subsequent years for a range of specified production quantities. The major provisions of warranty requirements set forth in the TACAN RFP are paraphrased as follows:

Part 1 -- Statement of Contractor Warranty

- Each TACAN set will be free from defects in material and workmanship and will operate in its intended enviroment in

[10] Major J. L. Higgins, USAF, Master's Thesis, *Long-Term Service Warranty Contracts: A Case Example of Gyroscopes purchased under Warranty*, Air Force Institute of Technology, September, 1972.

accordance with the specifications of the contract.

- Any set not meeting such warranty will be returned to the contractor's plant or designated repair facility at the expense of the Government and will be repaired or replaced at contractor's sole option, at contractor expense, so as to operate in accordance with said specifications. The contractor will ship the repaired or replaced item back to Government in an appropriate shipping container, freight not allowed.
- The contractor is under no obligation for loss or damage resulting from fire, explosion, flood, crash, enemy, etc., or for units whose seals are broken outside contractor's control. The contractor will not be liable for special consequential or incidental damages to Government property.

Part 2 -- Contractor Obligations

- All contractor-initiated ECPs for the TACAN set will be at no change in contract price.
- The contractor will have warranty-period information displayed on the units, showing the following:
  - Action to be taken on verifying failure
  - Failure-data recording
  - Packaging and shipping information
- A 30-day turnaround time (repair) is specified.
- Records by serial number for each unit under warranty will be maintained by the contractor. These records will include date shipped, date failed, date received, and date reshipped, with corresponding elapsed-time-indicator readings as well as the warranty period used.
- The contractor will place these warranty provisions in all technical manuals that provide coverage for this TACAN set.
- The contractor will have continuing responsibility for any unit received on or before the last day of the warranty period.

Part 3 -- Government Obligations

- The Government will, to the extent possible,
  - Test all sets at point of removal prior to return to contractor.

- Furnish maximum failure-circumstance data and test readings correctly recorded on AFTO 211 or equivalent.
- Utilize approved container and packaging.
- Return unit within 60 days of failure although the warranty will still be valid if the unit is not returned within 60 days or failure-circumstance data are not furnished.

- Since the warranty provides high contractor motivation for total cost control, the Government agrees that all no-cost ECPs submitted in accordance with MIL-STD-480 will receive special expeditious processing through the approved cycles. Any such ECP shall automatically be approved by the Government 30 days after receipt by the TCO except as notified in writing.

Part 4 -- Miscellaneous

- The Government representative at the plant will be notified when repair may not be covered by warranty.
- Instructions will be given for the disposition of units not considered to be economically repairable.
- The Government will provide equitable adjustments in price for negotiating repair not covered under warranty.
- If repair time exceeds specified turnaround time, the warranty shall be extended day-for-day for each day in excess.
- Removed materials will become the contractor's property as provided in the disposition clause above.
- Any unit that falls within the provisions of the disposition clause or is declared lost shall have an equitable adjustment in contract price for the unused portion of the remaining warranty.
- The Government will not be required to provide facilities, tooling, or equipments of any type for contractor performance under the warranty.
- The contractor will be required to correct deficiencies in accepted units at no change in price even though a failure has not occurred.

Part 5 -- Data Requirements

- To evaluate the extended-warranty procurement concept, the contractor will provide the following data items:
  - Warranty data report issued every six months containing (1) population information on all delivered items, including serial number, of each TACAN set repaired or replaced under

warranty, showing ETI and date and time of receipt and reshipment; (3) analysis of TACAN failures, including modes, trends, or patterns of failure from field usage, and recommended or projected action covering correction action; (4) detailed record of all TACAN sets dispositioned during preceding six-month period; (5) other pertinent data, facts, or information at discretion of contractor.

•• Warranty effectiveness study, issued annually. will contain: (1) report of experience and conclusion, if appropriate, regarding the effectiveness of the warranty concept applied by this contract; (2) recommendations and suggestions regarding warranty-clause provisions that may be of mutual benefit to the Government and industry in future procurements. The initial warranty period of 24 months will extend for all production units subsequent to the acceptance and delivery of the last production unit.

As noted at the outset of this discussion, AN/ARN-106 is currently being developed. The decision to include a warranty as part of the production contract remains to be made. At this time, it appears that project personnel view the use of warranties favorably.

4.2.2.5 USAF-OCAMA

OCAMA procured a flight director system (FD-109) to be retrofitted into the KC-135 aircraft. A contract was awarded to Collins Radio for their system, which, in effect, represented a modification of their standard flight director with a computation function added to provide a rotation and go-around capability.

The contractual agreement provided for a two-year failure-free warranty plus guaranteed life-cycle cost. The contractual values were predicated on achieving an MTBF of about 420 hours.

The unit, when initially deployed, achieved an MTBF in the vicinity of 100 hours. The reliability has since grown to about 250 hours, still falling short of the original figure. However, it is understood that some disagreement has arisen between the Government and the contractor regarding the use of flying hours alone or flying hours plus ground time in the computation of MTBF.

4.3 CONTRACTOR ACCEPTANCE OF WARRANTIES

One of the major questions of concern in accomplishing the interviews with equipment vendors was the degree to which vendors would be willing to respond to equipment procurements that contain warranty provisions. As expected, enthusiasm for warranties ranged from poor to highly favorable. However, all vendors queried indicated that they would respond if those were the conditions imposed in the procurement. Those vendors who

favored the use of warranties felt that it constituted an ideal mechanism for them to observe directly how their products performed in the use environment and placed them in a position to improve their product to gain wider acceptance. Those less optimistic about the use of warranties felt that it could become a marketing gimmick and as such would be subject to escalation, with more and greater requirements being imposed as a result of the competition to sell products.

All vendors interviewed felt that it was highly important that the use environment be clearly specified to permit adequate pricing of the warranty. Proper specification would identify the aircraft in which the avionics would be installed and provide a reasonable estimate of the expected flying program for that aircraft. They felt that equipments could be purchased for multiple application as long as the proportion of each application was clearly identified.

Most vendors queried indicated that they would be extremely reluctant to permit military maintenance organizations to accomplish warranty repairs for which they were liable for reimbursement. Some, however, did express an open mind on the subject and indicated that it might be feasible after more experience was acquired concerning military maintenance facilities, and that such concepts could be evolved, perhaps augmented with technical representatives located at the military facilities.

4.4 MATERIAL FLOW UNDER WARRANTIES

Repair/replacement actions for most warranty contracts that have been thus far implemented in the military have been accomplished at the vendor's plant. Failed items are normally sent through the traditional supply lines to the controlling depot. At this point, they are then directed to the vendor's plant. Shipping costs have been borne by either the vendor or the government, depending on the terms of the warranty contract. Such a flow is no doubt the easiest to implement since it makes use of the normal supply channels. However, the time required for a unit to transit this channel can be a matter of two to three months, constituting a lengthy pipeline that must be filled with added spare units to maintain equipment on site.

An experimental program is being implemented within the Navy that entails direct shipment from the using squadron to the vendor's repair facility, with replacement being made in the same manner.[11] At the using operation, after the decision has been made to return the unit, a message is sent to the vendor that a unit is being returned. The vendor, upon receiving this message, initiates action to ship a replacement unit within a prescribed period of time (24 hours). The replacement item is drawn from a bond room that he maintains to house spare units previously purchased by

[11] The Closed Loop Aeronautical Management Program (CLAMP) is being used by the Navy to support A7-E aircraft.

the government. Upon receipt of the failed item, the contractor will repair it and place it in the bond room for future use. Although, as mentioned, this program is being tried initially this year, the concept is considered to have merit and should make a marked reduction in the pipeline time associated with the support of a remote unit.

The use of authorized shipping containers is of paramount importance. Several vendors mentioned that one of the major problem areas was in-transit damage. The use of proper containers corrected this problem. To be successful, a warranty program must be established to assure that properly designed containers are secured and used for material handling.

4.5 PROCUREMENT TESTING REQUIREMENTS

The requirements for continued testing (as currently dictated by the array of military specifications) when a warranty is in effect have been questioned. One vendor indicated that in producing products for the commercial market he performs the equivalent of the Mil-Spec tests at considerably lower cost because of his ability to organize them optimally and the elimination of the need to provide extensive documentation concerning their outcome. He further noted that such formal testing could increase his product's cost by as much as 65 percent. This opinion, however, was not fully shared by other vendors. Some stated that some form of testing was definitely needed and that the military specifications were a reasonable, consistent basis for meeting testing requirements. It was also noted that some of the major airlines are performing in-house testing prior to the purchase of a product to verify its performance capability. In addition, some airlines are requiring a minimum amount of burn-in testing time prior to the delivery of a new or repaired item. The general consensus that can be drawn is that some form of testing is definitely required prior to product deployment but that with a warranty perhaps its magnitude could be decreased somewhat and that the extensive documentation now required could be reduced.

4.6 CONFIGURATION CONTROL

One of the fundamental premises of the failure-free warranty concept is the ability of the contractor to implement reliability improvements he considers appropriate subject to the approval of the cognizant military technical activity. Most warranty contracts of this type have provisions requiring that the Government respond to such proposed no-cost ECPs within a specified period of time (30 days). It may be argued that such changes could lead to a proliferation of system configurations. Limited experience, however, shows that the opposite has been encountered. Since the contractor is motivated to increase reliability, he extends every effort to modify the item to achieve this end.

4.7 MANAGEMENT DATA

Support of each of the military warranty programs reviewed required that the contractor supply the Government data concerning the warranty status of contracted items. In the cases examined, the contractors have combined service-generated data with records they have gathered from the repair operations to develop the needed management information.

Higgins, in commenting on the Air Force data system, noted that, in combination, existing data systems supply most of the needed information for warranty administration.[12] Major data systems he believed could contribute were:

D073 -- Management of Items Subject to Repair

D041 -- Repairable Consumption Item Requirements System

D147 -- Repairable Item Movement Control System

6068 -- Depot Repair Cycle Management System

D057 F&G -- Advanced Configuration Management System

Of these, he believed that D057F, in combination with D041, formed the main data sources. Other data sources included G072, D056, AFM 66-1, and the Air Force Recoverable Assembly Management System. He also observed that current data systems were developed on a commodity basis rather than on a system basis, thus preventing ready identification of the performance of a specific equipment type by a single manufacturer.

As noted in the preceding discussion concerning the ASO-Lear Siegler gyro-repair warranty contract, service data systems are used in combination with contractor-generated data. Table IV describes the type of reports, and their contents, that are currently being developed to support this warranty program. The data package is more comprehensive than would normally be required to administer a failure-free warranty program, but the added displays related to failure-mode information are considered quite useful for reliability engineering investigation.

A warranty program requiring demonstration of a system parameter such as MTBF would require reporting of not only failure information but success hours as well. Since aircraft-utilization hours are commonly reported, it is necessary to estimate operation in hours by applying the ratio of ground hours to flying time. Additionally, classification of failures becomes more critical and more definitive reporting is required to assure that both parties can mutually agree to decisions made.

In summary, current military data systems augmented by contractor inputs can support warranty programs. It would be desirable, however, to

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[12] J. L. Higgins, *op. cit.*

TABLE IV

LEAR SIEGLER-ASO WARRANTY REPORTS

<u>FFW Warranty Program Report.</u> Displays on a cumulative basis all available information relative to a given repair/overhaul action on a given unit by FFW serial number. Data displayed may be categorized as identification information, incident information, receiving information, repair information, and shipping information.
<u>System Status Summary Report.</u> Lists pertinent in-out types of data in FFW serial-number sequence. It displays, on a cumulative basis, certain specific information relative to a unit's identification, receipt, shipment, and FFW program status with a specific indication of remaining warranty hours.
<u>Trace Data Reports.</u> Provides specific data showing the time sequence of activity for each FFW unit. This permits tracing each unit with all information sequenced by calendar time. For each serial number, a complete history of in, out, installed, and removed data is sequenced with action dates and clocked hours.
<u>Low-Activity-Unit Summary Report.</u> Lists, in order of descending number of days, those FFW units for which no activity has been reported within 90 days after shipment from LSI or 60 days after a reported installation.
<u>Configuration Data Report.</u> Lists configuration status of each FFW gyro by serial number.
<u>Failure-Mode Distribution.</u> Displays a frequency distribution indicating failure mode versus frequency of occurrence.
<u>Failed-Parts Summary Report.</u> Identifies the specific parts replaced corresponding to failure modes and reason for replacement. This report displays failed-part information by part number, indicating circuit identification, failure mode, failure cause, corrective action, and expected failure-rate change.
<u>Low-Activity-Unit Trace Data Report.</u> Lists units in descending order of time of inactivity but contains the known detailed information to assist tracking a unit.
<u>Turnaround Time Report.</u> All the FFW units that leave LSI and return again after a failure are included in the analysis of turnaround time.
<u>Aircraft Utilization Report.</u> Lists aircraft utilization, reported in sequence by aircraft BU number. Each aircraft is reported separately, with all the data-bank information related to that aircraft within time sequence.
<u>Stricken-Aircraft Reports.</u> FFW gyros lost due to aircraft strikes, with the known activity prior to strike.
<u>Units Presumed Lost Report.</u> Abstracts those FFW gyros presumed lost.
<u>Parts Usage Summary.</u> Shows, by part-number sequence, the total usage of each part and how often it is used per unit and per repair cycle. It displays part-replacement history on a cumulative basis. Display format is one report line per replaced part drawing number.

review current data systems in the light of future warranty experience to identify data requirements, both military and contractor, more completely.

4.8 ITEM MARKING

Equipments procured under warranty agreements should be adequately marked to indicate that such coverage is available. Appendix II presents a list of data that should be considered in warranty marking. The Air Force has proposed a revision to MIL-STD 129-E calling for marking shipping containers for warranted items. Exhibit 1 illustrates the proposed change. It is understood that the proposed change is now being coordinated within the total DoD community to achieve a standard warranty marking method. MIL-STD 130, which covers item marking, does have provision for warranty information marking.

4.9 WARRANTY CONTRACTING

Initial efforts to fund warranty programs have encountered some difficulty, as pointed out in the examples cited. The basic question is whether to use production funds or operation and maintenance (O&M) funds. Since O&M funds may be appropriated on an annual basis only, purchase of multi-year warranties constitutes a further problem. Recent informal information from DoD authorities indicates that use of production funds will be encouraged for new procurements and that incrementally funded O&M monies will be used for renewal warranties and those associated with overhaul and repair.

It should be noted that ASPR 1-324.2b states that "a warranty clause shall not be included in cost reimbursement type contracts, since the warranty aspects of the clause 'Inspection of Supplies and Correction of Defects' in ASPR 7-203.5 are sufficient to protect the interest of the Government." Paragraph 7-203.5b states that in a cost-reimbursement type supply contract, the cost of any replacement or correction shall be included in Allowable Costs. Thus it can be concluded that a long-term warranty contract must be made on a fixed-price basis secured either through negotiated or advertised procurement. The DoD working group on contract warranties recommended that warranties be considered only for procurements subsequent to the initial and advanced development phases, which are more amenable to fixed-price contracting.

The DoD committee also recommended that the ASPR committee recognize that "it should be the DoD policy, when post-acceptance warranties are employed to recognize a reasonable costing factor for the deferred liability so created." Within this context it appears highly desirable that warranty cost form a separate line item in all procurements to permit these costs to be clearly identified and available for cost-of-ownership analysis.

A series of changes is now being considered for incorporation into ASPR 1-324 dealing with warranties.[13] Highlights of these possible

[13] Recommended by ASPR Subcommittee on Warranty.

PROPOSED MIL-STD-129E

ESSENTIAL COMMENTS.

ADD PARA 5.2.2.12 - WARRANTED ITEMS. When applicable, boxes or packages containing warranted items shall be marked as follows: (SEE FIG 4___)

THIS ITEM WARRANTED FOR. ______________________
(Days, Months, Hours, Miles)

WARRANTY TERMINATES. ______________________
(Date, Hours Operation, Miles)

Procurement Instrument No. ______________________

ADD 5.2.2.12.1 - Warranty information shall be marked with green letters (Fed. Std. 595 Color No. 14187) on yellow background (Fed. Std. 595 Color No. 13655) and shall be included with identification marking.

ADD FIG 4___

YELLOW BACKGROUND
(Fed. Std. 595
Color No. 13655)

GREEN LETTERS
(Fed. Std. 595
Color No. 14187)

THIS ITEM WARRANTED FOR__________
WARRANTY TERMINATES____________
CONTRACT NO.__________________

FIG. 4___ WARRANTED ITEM LABEL

REASON: Extensive use of warranty clauses in DOD contracts has generated an urgent need to standardize the information to be marked on the item and unit and intermediate containers. Such information on the containers is necessary to identify and manage items procured with warranty.

EXHIBIT 1
PROPOSED MIL-STD-129E

changes included:

- ASPR 1-324 has been modified to clarify the DoD policy on when a warranty should be used and how it should be structured for better enforcement. The many factors now listed in ASPR regarding the decision to use warranties have been reduced to four basic factors -- nature of the item, cost of the warranty, potential administration of the warranty, and trade practice.
- New guidance has been included regarding the preparation of warranty provisions when use of a warranty other than one of the sample warranty clauses is required. These guidelines include coverage of the extent of the contractor obligations, the duration of the warranty, notice provisions for administration of warranty, and administrative techniques to enforce the warranty.
- The only significant policy change reflected in ASPR 1.324 is the citation that implied warranty of "merchantability" and "fitness for a particular purpose" are negated in DoD contracts. This has also been carried out by the recommended change to Section 7, Part 1.
- The only other significant change from current ASPR coverage contained in the report is the recommendation that a provision be incorporated into contracts containing warranty provisions to the effect that normally the time period established for discovery of defects under the warranty provision will also be applicable to discovery of defects under the "latent defects" provision of the inspection clause. It should be required that this provision be inserted in any warranty clause included in a contract as authorized by ASPR 1-324.

Action will be taken to coordinate these changes with industry and other Government agencies.

R. E. Black conducted an audit of supplemental military documents related to warranties.[14] Table V highlights the documents found. His overall conclusion was that only minimal information was available to guide service personnel in the establishment and administration of warranties.

4.10 Warranty Administration

Most warranty agreements are written in such a way that an interface is created directly between the user and the vendor. However, in the case of major weapons systems, it is possible that such agreements will be placed with the prime, who in turn passes on warranty requirements to his

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[14] R.E. Black, *Study of Warranted Items*, Management Intern Project, DSAS-AC, September 1972.

TABLE V

SUPPLEMENTAL WARRANTY PROCEDURES

Agency	Provisions
Army	None -- study in progress.
Navy	NAVAIRINST 4330.16 -- NAVAIR Field Contract Administrative Manual. Provides instructions for handling warranty items. NAVAIRINST 4275.2 -- Detailed instructions on use of warranties. NAVORD 4275.2 -- Similar to NAVAIRINST 4275.2
Air Force	AFM 67-1, Vol. 1, Part 1 -- Section V provides step-by-step procedure on determination to use warranties.

suppliers In the case of the airlines, the aircraft manufacturers will negotiate the warranty agreements with their suppliers, but the agreements will be passed on to the aircraft purchaser and subsequent administration will be accomplished directly between the airline and the vendor. Military warranty experience has been much more limited, and most known warranty agreements have been directly between the vendor and the using agency.

A warranty claim is initiated with the using activity, which, upon performing the appropriate equipment task, determines that the system is in non-compliance. Action then must be taken to package the item properly and prepare it for shipment. Most military warranty plans in effect call for the item to be sent back to the normal supply channels for dispatch to the supplying contractor. As noted above, methods that would permit shipment from the using activity to the contractor are encouraged.

Upon receipt at the vendor's plant, the unit undergoes receiving inspection to ascertain if the item is admissible under applicable warranties. The major reason for excluding an item is that either the operational or the calendar time has expired. Assuming that this has not happened, the material condition must be established to see if it falls within the failure definitions defined by the warranty agreements. Most agreements exclude damage in shipment, unauthorized modifications, etc. The several successful contracts that have thus far been accomplished have established the local plant DCAS representative as the final authority for determining whether an item is admissible. In the event the contractor disagrees with the DCAS representative's judgment, the standard contractual disputes clause can be exercised.

Once an item has been admitted with an acceptable warranty, it is the contractor's requirement to repair the item within a specified period. His failure to do so may invoke penalties that have been established concerning turnaround time. It is noted in the case histories presented that penalties

comprising monetary payment or the provision of additional warranty days have been used where the specified turnaround time has not been achieved.

Warranty agreements that, in effect, guarantee stated levels of performance such as MTBF require that proper data be acquired to exercise appropriate judgment. The scope of such information was discussed in Subsection 4.7. As noted, because of problems with the current military data systems, this form of warranty has seen little use.

In the event the contractor does not meet his obligation, default proceedings may be instituted against him. An alternative avenue would be the requirement that potential contractors establish performance bonds in the event of default. None of the cases examined required such extensions.

SECTION V

ASSESSING THE ECONOMIC VALUE OF WARRANTY

5.1 INTRODUCTION

Although warranties offer a potential benefit to the military user, it should not be assumed that this procurement vehicle is applicable to all avionics procurements. High-reliability units, already in the inventory, that can be quickly and cheaply repaired represent a case in which a long-term warranty is probably not economical. This study has considered the question of determining whether a warranty is economically attractive and, if it is, the best warranty period. A preliminary Warranty Life-Cycle Cost Model was developed for a failure-free type of warranty. This model, while not complete in all respects, can serve as a good vehicle for providing initial answers to the economic question. The assumptions, development, and details of this model are described in Appendix III. The basic approach and some highlights are presented in this section.

5.2 THE GENERIC LIFE-CYCLE COST MODEL

A generic model for life-cycle cost associated with acquisition and maintenance can be written as follows:

Life Cycle Costs over (O, T) = Number of units bought × price per unit
+ Expected number of failures over (O, T) × average cost per failure
+ Maintenance support costs over (O, T)

For any avionic equipment, reliability growth is possible through engineering design, quality, or production changes, which we will generally refer to by the term reliability modification. Reliability and reliability growth influence the number of units (spares) purchased and the number of failures that will occur. The modification necessary to achieve the reliability growth is also generally a major capital investment.

5.3 LIFE-CYCLE COST -- NO WARRANTY

We now extend the generic model to consider life-cycle costs over a period (O, T_w) for a no-warranty procurement, with consideration given to reliability modification, initial and recurring support costs, and amortization. The equation we developed for a no-warranty case is as follows (the "0" superscript is used to denote a no-warranty procurement):

$$LCC^0_{T_w} = N^0 C_P A_{T_w} + C^0_{MOD} + C^0_{DMC} + C^0_{ISU} A_{T_w} + C^0_{RSU} \cdot T_w$$

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where

$LCC^0_{T_w}$ = life-cycle costs over $(0, T_w)$ for a no-warranty procurement

T_w = calendar time in months

N^0 = number of units purchased

C_P = purchase price per unit

A_{T_w} = amortization factor for $(0, T_w)$ = T_w/Expected equipment life

C^0_{MOD} = expected amortized costs of reliability modification

C^0_{DMU} = direct user maintenance costs

C^0_{ISU} = initial support costs

C^0_{RSU} = monthly recurring support costs

Submodels are developed in Appendix III for obtaining N^0, C^0_{MOD}, and C^0_{DMU}, all three factors depending on initial reliability and the time and effectiveness of reliability modification. Since initial reliability (expressed by failure rate in the model) is rarely known precisely, we allow for a prior distribution of initial failure rate:

$$(p_i, \lambda_i) \text{ where } p_i = \text{Prob } [\lambda = \lambda_i], \sum_i p_i = 1.0.$$

5.4 MODEL DEVELOPMENT

The step-by-step development of the overall model is as follows:

1. User Cost Per Failed Unit, C^0_{FU}. This is the direct cost per failure, including repair labor hours, materials, and necessary shipping/handling costs.

2. Reliability Improvement Through Modification, M. If λ is the failure rate of the unit, we assume that a reliability modification will reduce it to $M\lambda$ $(0<M<1)$. We have suggested one possible model for obtaining M as a function of current failure rate and specified rate.

3. Modification Time Distribution, $f(T_m)$. The time at which a reliability modification can be introduced is assumed to be a random variable that has a two-parameter exponential distribution.

4. Cost of Modification, C(M). The cost of modification is assumed to be a function of the improvement factor, M. On the basis of limited data, we have developed one such function in the interest of completeness.

5. Procurement Size, N_o. The number of units purchased is based on the number of operational units required plus the expected number in the pipeline (using Palm's equation). To obtain the average number in the pipeline, we calculate the expected failure rate over the equipment lifetime, considering the initial failure rate (or prior distribution of failure rate), the probability and time of modification introduction, and the modification improvement. Consideration is also given to a minimum spares requirement.

6. Modification Strategy, T_i^0. We assume that the user will request a modification only if the cost of such modification is less than the expected savings in repair costs. The development yields a time interval (T_α, T_i^0) over which modification is profitable. T_α represents the minimum time before a modification can be introduced. T_i^0 represents the maximum time for modification if $\lambda = \lambda_i$.

7. Amortized Modification Costs, C_{MOD}. The expected modification cost is based on the initial failure rate, the cost for modification if $\lambda = \lambda_i$ [i.e., $C(M_i)$], the probability that a modification is performed over $(0, T_w)$, and the amortization factor based on the expected time of modification if a modification is performed over $(0, T_w)$.

8. User Direct Maintenance Cost of C^0_{DMU}. The cost is equal to

$$N_o \bar{\lambda}^0 C^0_{FU} H_o T_w$$

where

N_o = number of operational units

$\bar{\lambda}^0$ = the average failure rate over $(0, T_w)$

C^0_{FU} = the cost per unit failure

H_o = the unit operating hours per month

T_w = the number of months under consideration

To calculate $\bar{\lambda}^0$, we consider the initial distribution, (p_i, λ_i); the possible improvement, M_i, associated with λ_i; and the probability that such an improvement will be initiated during the period $(0, T_w)$.

9. Support Costs, C_{ISU}, C_{RSU}. These costs involve test equipment, training, handbooks, etc., that must be incurred initially, plus recurring costs such as administrative costs and retraining.

5.5 LIFE-CYCLE COST WITH WARRANTY

For a warranty procurement, we assume that the user incurs the same types of cost as for the no-warranty case except for direct reliability-modification cost. Naturally, his direct maintenance costs will be much less and so will his initial support costs, especially if the equipment is new to the inventory. On the other hand, the user's recurring support costs will generally be greater because of the cost of warranty administration. We also note that all costs expected to be incurred by the contractor will be included in the contract price, burdened by fee and risk factor.

These considerations lead to the following life-cycle cost equation (the "1" superscript is used to denote a warranty procurement):

$$LCC^1_{T_w} = N^1 C_P A_{T_w} + [C^1_{MOD} + C^1_{DMC}]\ R(T_w)\ (1 + P)$$

$$+ C^1_{DMU} + C^1_{ISU}\ A_{T_w} + C^1_{RSU}\ T_w$$

where

C^1_{DMC} = contractor direct warranty repair costs

$R(T_w)$ = risk factor contractor applies to costs for a warranty period of T_w months

P = contractor fee

C^1_{MOD} = contractor costs for modification, discounted and amortized

All other symbols represent the same factors as for the no-warranty case except that the numerical values will generally be different, as discussed above.

5.6 ILLUSTRATIVE APPLICATION

In Appendix III, four sample procurements are presented to illustrate the application, and the type procurement, data inputs, and results are discussed in some detail. We present here highlights from one of these illustrative examples to indicate the utility of such a model.

This procurement represents a small purchase of a moderately priced, moderate-MTBF unit that is already in the Air Force inventory. An attempt was made to use as many data on the existing Air Force A24G-26 gyro warranty procurement as possible, but not all required data were available (e.g., the current MTBF of the gyro under warranty was not obtainable at the time of this study).

Table VI lists the data-input requirements of the model and the values we used for this sample application. A conversational time-sharing program in the FORTRAN language was developed to exercise the model. A number of reliability and life-cycle cost factors are calculated and outputted. Of particular interest are (a) the warranty cost savings (loss) for a warranty period of T_w; and (b) the warranty indifference price, which is the unit purchase price (including a warranty cost increment) that yields a life-cycle cost for a warranty procurement over $(0, T_w)$ that is equal to the equivalent life-cycle cost for a no-warranty procurement.

Figure 4 shows the warranty cost savings as a function of the warranty period. For this illustrative application, the maximum saving of $12,550 occurs when T_w = 24 months, which is approximately 4.4 percent of the cost without warranty.

Figure 5 shows how the warranty indifference price varies with the warranty period.

Table VII presents the computer output for a warranty period of 24 months.

5.7 MODEL-IMPLEMENTATION ASPECTS

While further developments of the life-cycle cost model are required (see Section 18 of Appendix III), we believe that the life-cycle cost approach for assessing the economic value of warranty is required and is possible. There is no question that warranties will involve additional acquisition cost and that such cost increments will increase with the warranty period. Should a warranty be used, how much it should cost, and what the best warranty period is are questions that can and should be answered quantitatively.

Warranty pricing is essentially a task not any more difficult than that which contractors and procurement officers face in establishing production costs and contract maintenance costs and in determining the required number of spares based on expected reliability/maintainability performance. The life-cycle cost model developed in this study provides a vehicle that both contractors and military procurement officers can use to make basic decisions on warranties and to establish a fair price.

TABLE VI

DATA INPUTS FOR MODEL APPLICATION -- GYRO PROCUREMENT

Data Element	Symbol	Procurement B Gyro	
		No Warranty	Warranty
Unit purchase price	C_P^0	6,040	-- †
Number of operational units	N_O	100	100
Operating hours per month	H_O	50	50
Equipment lifetime (months)	T_L	120	120
MTBF distribution	$(p_1;\theta_1)$	.5;900	.5;900
	$(p_2;\theta_2)$	.5;1350	.5;1350
Specified MTBF	θ^*	2,240	2,240
User labor hours per failure	H_{LU}	60	2
User labor rate per failure	C_{LU}	15	12
User shipping cost per failure	C_{GU}	20	10
User material costs per failure	C_{EU}	250	0
Contractor labor hours per failure	H_{LC}	--	40
Contractor labor rate per failure	C_{LC}	--	16
Contractor shipping costs per failure	C_{GC}	--	10
Contractor material costs per failure	C_{EC}	--	175
Minimum modification time (months)	T_α	3	3
Failure rate improvement if $\lambda = \lambda^*$	M^*	.90	.90
Minimum value of F.R. improvement factor	M	.25	.25
Rate for modification introduction	d	.042	.042
Factor to adjust modification costs for warranty	A	--	.80
Minimum number of spares	N_X	20	20
Pipeline time (months)	T_P	2.0	2.0
Risk factor	r	0.03	0.03
Contractor fee	P	0.10	0.10
User initial support costs	C_{ISU}	20,000	20,000
User recurring support costs	C_{RSU}	500	800

†Calculated by model.

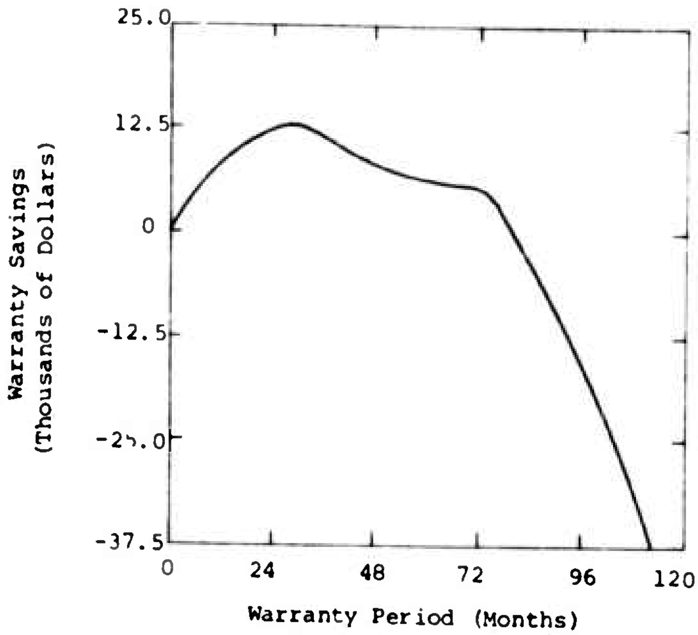

FIGURE 4

WARRANTY SAVINGS VS WARRANTY PERIOD,
GYRO PROCUREMENT

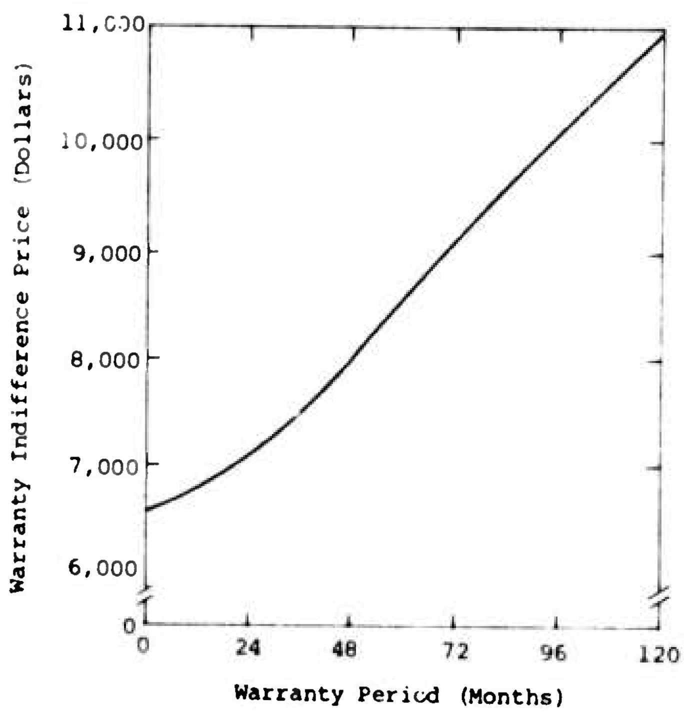

FIGURE 5

WARRANTY INDIFFERENCE PRICE VS WARRANTY
PERIOD, GYRO PROCUREMENT

TABLE VII

SAMPLE COMPUTER OUTPUT

```
 #### WARRANTY PERIØD =  24 MOS. ####

MØD.TIME  INTERVAL,(MØS)
     NØ-W.  WRNTY.
  1   21.0    0.
  2   21.0    0.

                        NØ WARRANTY   WARRANTY

AVG. MTBF-(O,TW)          1146.75     1030.00

DIRECT M COST-USER         122433        3778

DIRECT M COST-CNTR.             0       91667

EXPCTD. MØD.CØST     TØTAL    AMØRTIZED
USER (K=0)           36388       4050
CNTR.(K=1)               0          0

                   TØTAL    MØNTHLY   TØT.SUP.  M .SUP.   UNIT
                  CØST(A)   CØST(A)   CØST(A)   CØST(A)   PRICE

NØ WARRANTY        287444     11977    138433     5768    6040

WRNTY  24MØS.      274912     11455     22978      957    6931

WRNTY.PRICE INCREMENT/YR.(PCT.)= 7.38

TØTAL COSTS W/Ø AMØRT.--NØ.W;W     915622     854752

WARRANTY SAVINGS (TØT.AMØRT.CØST)  $    12532

INDIFFERENCE W.PRICE=$  7036 ( 8.24 PCT.)
```

SECTION VI

CONCLUSIONS AND RECOMMENDATIONS

6.1 GENERAL CONCLUSIONS

The extensive airline experience with warranties on avionic equipment and the limited but successful military experience definitely establish the value of this type of procurement. With a warranty, a supplier's profits are *directly* related to the reliability performance of his product. The current military procurement methods do not provide this relationship. In fact, it has been argued that the military vendor achieves maximum profit by delivering the lowest reliability that will be accepted. Since the standard military procurement environment does not adequately encourage achievement of high reliability, the using activity suffers the additional support costs associated with reliability problems with little or no contractor relief. In addition, if a modification to improve reliability is deemed necessary, this cost is also directly borne by the military buyer. Although the airlines also suffer monetary losses when equipment fails, the continuing competitive airline market that exists because of standardization and interchangeability tends to make airline avionics suppliers much more reliability and support-cost conscious, especially when almost all procurements do include warranty provisions.

The military procurement process definitely uses competition for both R&D and production contracts. (One interviewee stated that production procurements have become virtual auctions, with low bidder taking all). The airlines have been able to foster a different type of competition. First, they maintain competition in design type into production through their form-fit-and-function specification. If one vendor's design is unsatisfactory, they can buy another vendor's product (design) and install it without aircraft modification. A second aspect of the competitive environment is that the product's performance is a factor in future procurements that the airline may make. These factors, coupled with the warranty effects on profit, provide the motivation to produce superior products.

If, as noted in Section III, a good summary statement on the purpose of warranty is that warranties extend a supplier's responsibility to include field performance, what are the benefits that will accrue in military procurement? The major benefits include demonstrated higher reliability and reduced life-cycle cost. Because a greater commitment is made by a contractor who enters into a warranty agreement, it is believed that the use of such provisions may discourage the marginal producers who now plague the low-price competitive-bid procurement situation. We basically believe that most of the warranty benefits airlines receive will extend to the military environment. It is emphasized, however, that in addition to warranty, there are other factors in the airline procurement environment that exert strong influences on avionics reliability, life-cycle cost, and contractor selection.

6.2 SPECIFIC CONCLUSIONS

Conclusions drawn from this investigation of warranty practices in the airlines and the military are enumerated below.

6.2.1 Warranty Use

Warranty practice is deeply rooted in U.S. commerce, tracing its history from implied warranties to expressed warranties in terms of the Uniform Sales Act and, more recently, the uniform Commercial Code. Airlines make extensive use of warranty not only for avionics procurement but for a wide range of other commodities.

6.2.2 Reliability Incentive

There is no certain answer to the question of how much reliability incentive warranties provide for airline avionics. Most vendors believe that there is definitely an incentive, but it is difficult to separate it from the incentive competition produces. Current vendor reliability practices concerning design, supplier control, production control, and test and inspection have evolved in conjunction with increased airline dependence on warranties. For the military, attempts to provide reliability incentive through reliability demonstration-test provisions and financial incentive/penalty contracts have not yielded the long-term success desired.

The current military approach is based on initial reliability. A failure on a demonstration test is often waived because of schedule commitments, or a contractor proposes a design or production change and is allowed a retest. Statistically, he will eventually pass the test even if the changes are of no value. More important, a controlled or semi-controlled test environment differs tremendously from military usage in the field. The fact that military suppliers will suffer reduced profit for failures that occur in the field during the warranty period must provide some positive incentive for reliability and also force them to consider the real use environment. The attractiveness of the strategy of "buying in" and reaping a large profit on spares and reliability design modifications is essentially eliminated.

6.2.3 Reliability Growth

Since the military supplier will suffer expense for failure of warranted units, he is deeply interested in introducing design/production changes that will increase the MTBF and will do so if the cost of such introduction is lower than the savings in warranty-repair costs. Also, if the supplier is performing the repair of warranty units, he is intimately aware of failure modes, patterns, and trends as they are occurring in field usage and is therefore more knowledgeable in developing appropriate modifications to improve reliability. One of the fundamental premises in the concept of encouraging reliability growth through warranties is the ability of the contractor to implement reliability improvements subject only to the *timely* approval of the cognizant military.

It is generally recognized that airlines obtain a higher reliability than the military achieves with comparable equipment. Data we have analyzed support this fact. For functional comparisons where accomplishment is provided by identical systems, the MTBF ratios generally favor the airlines by a magnitude of 2 or 3 to 1. Comparisons of functions in which a military-conceived system is related to an airline-formulated specification shows that these ratios are on the order of 5:1 to 8:1. It is believed that the airline's ability to maintain competition into the equipment production phase accounts for a major portion of these observed ratios. It is also held that the use of warranties has clearly contributed to this observed achievement.

6.2.4 Maintainability Incentive and Growth

The maintainability characteristics of the equipment will benefit from a warranty provision for the same reasons that the reliability benefits. Any reduction in labor hours or materials in repairing equipment will increase contractor profits. On the Navy/Lear Siegler warranty contract on gyro overhaul, the labor hours were reduced from 80 hours to 40 hours by the contractor with apparently no reliability reduction. Shorter contractor repair times yield better equipment availability to the user and will carry over to some extent if and when the user assumes repair responsibility.

6.2.5 Minimal Initial-Support Investment

If the supplier is to provide repair services over the warranty period, savings in repair facilities and equipment, handbooks, training, and spare parts inventory will accrue. The investment for such items can be substantial. If the options for warranty renewal exist and are exercised, such investment need not be directly made, with costs possibly being spread across a broader customer base. Even if the military using activity is to take over the repair burden after the initial warranty period expires, it can gradually build up a maintenance capability that will take advantage of the supplier's experience. Also, the military may take over maintenance after reliability and other modifications have been introduced. Since support investment will be geared to the current, stabilized design, the amounts now spent on changes to test equipment and maintenance manuals and retraining of service personnel will be saved.

6.2.6 Life-Cycle Cost Control

With a warranty provision that applies over a significant time period and with options for renewal, the military user can be much more confident in controlling costs for a significant number of life-cycle cost elements. This is a simple recognition of the fact that a major portion of the repair funds has already been allocated with a warranty provision. If appropriate analysis of a warranty cost proposal has been made, presumably these costs are not significantly greater and probably are lower than corresponding cost without warranty.

6.2.7 Contractor Benefits

If warranties benefitted only the user, there would be little likelihood of their acceptance by manufacturers. In pricing the warranty-cost increment, the contractor estimates all costs associated with the warranty clause, and to these he adds his normal profit factor, perhaps augmented by a risk factor dependent on the length of the warranty period. If the reliability/maintainability characteristics of his product are equal to the initial estimates used for pricing, the contractor realizes a fair profit. Since these initial R/M estimates will generally require military approval, the user will also be satisfied. If the product exhibits better R/M than anticipated (perhaps after "no charge" contractor-introduced modifications), contractor profits are increased and the military user achieves better operational effectiveness than expected at no additional cost.

These remarks are not merely hypothetical allusions. The Navy/Lear Siegler warranty contract on gyros discussed in Section IV has resulted in reduced Navy hourly support costs and improved MTBF, and it has yielded the contractor a very satisfactory profit.

In addition to the profit potential, a warranty provision offers to a contractor a long-term stabilized work flow. Furthermore, by continued attention to the operational reliability and maintainability characteristics of equipment in the military environment, the contractor accumulates expertise that should yield benefits in new procurements.

6.2.8 Economic and Military Manpower Impact

If warranties are applied on a large scale, a significant portion of the dollar expenditure for equipment maintenance will transfer directly to the civilian economy. The economic impact of this possibility is certainly an area for further research. In the same vein, extensive warranty use will tend to reduce greatly the requirements for military maintenance personnel. With the recent elimination of the draft, an approach that reduces the need for skilled military personnel offers attractive possibilities.

6.2.9 Design to Cost

We have encountered some comment that including a warranty clause in a procurement contract would conflict with the prevailing "design to cost" philosophy. We believe that a warranty provision not only complements design-to-cost but provides, finally, a strong rationale for the low-bidder approach to source selection.

With design-to-cost, unit purchase price becomes the equivalent of a performance parameter. Purchase price plus the increment due to warranty yields a much more relevant dollar investment value in the low-bidder concept than purchase price alone. The purchase price plus the warranty increment would actually represent a significant portion of the life-cycle costs that accrue over the warranty period. We therefore believe that there is merit to requiring separate cost proposals for purchase price and warranty-price increment in order to evaluate conformance to an existing

design-to-cost requirement and still provide a basis for realistic cost evaluation.

6.2.10 Warranty Application

To achieve a more workable warranty, it is important that the agreement be established with as few exclusions as possible. Although this may be more costly initially, it is believed that in the long run it will be more profitable because it eliminates disputes and the situation in which material is tied up while the disputes are being resolved. Additionally, broader coverage is expected to reduce the administration cost attendant to monitoring the warranty program.

Although the warranty period that optimizes the life-cycle cost savings is a function of several variables, it is important that the warranty period be established for a long enough period to permit securing the benefits that a warranty may provide.

To use warranty effectively, the product must have reached at least initial design stability, and it must be possible to make reasonable estimates of its expected performance characteristics. This clearly indicates that warranties should be applied to only production contractual situations.

Since warranties represent a prepaid maintenance cost, if proper claims are not exercised, then this represents money spent for which no return is achieved. To be effective, it is necessary to establish the proper administration procedures in association with securing warranty contracts.

6.2.11 Warranty Cost

It is clear that the warranty provision costs the contractor additional funds, which are generally added to the initial purchase price. These costs typically may range from 4 to 10 percent of the initial acquisition price per year of coverage.

The airline industry is convinced that warranties pay dividends over the added cost that they place on acquisition. Further, they view warranties as a type of insurance that provides protection against systems which may give them serious problems.

6.2.12 Warranty Acceptance

Military-equipment contractors will generally be willing to respond to procurements containing warranty provisions. However, they all stressed the importance of clearly specifying the use environment. Most contractors would be reluctant to permit military maintenance organizations to accomplish warranty repair for which the contractors are liable for reimbursement.

6.2.13 Warranty Application Problems

We now consider the possible special considerations, problems, and disadvantages associated with warranty clauses in military procurement of

avionic equipment. A detailed discussion of each is presented in the following paragraphs.

6.2.13.1 Disputes

Unless a warranty provision is very broad in coverage, the vendor may honestly believe that a warranty claim is not valid. This situation will occur most frequently when the equipment fails because it is exposed to environmental stresses that exceed anticipated levels. User damage caused by mishandling, damage while in transit, and questions involving warranty termination may also lead to disputes.

With regard to environmental stress, the approach that avoids most disputes is to include all failures as relevant except those types which are specified in detail in the contract. Besides the advantages of minimizing disputes, this type of broad coverage forces the contractor to consider environmental extremes in his design/modification strategy. It would be quite natural to exclude failures due to obvious gross abuse, combat damage, unauthorized or improper user maintenance/repair actions, etc.

The policy of providing the resident Defense Supply Agency Quality Assurance Representative with authority for judging the validity of a warranty claim has worked well in several military warranty procurements. The contractor naturally has the right to appeal under the military contract provisions

6.2.13.2 Warranty Administration

There is no question that administration of a contract with warranty provisions introduces additional administrative problems if for no other reason than that it represents a departure from current practice. Although shipping a warranted unit back to the vendor for repair should not involve any greater procedural difficulty than shipping a non-warranted unit back to a depot for repair, some special administrative actions will be required. First, it is most important that the warranty items be clearly identified to minimize losing warranty benefits. Maintenance and supply personnel must also be trained in handling and shipping warranted units so as not to void the terms of the warranty. The special data requirements of warranty clauses will also require administrative action. Finally, responsibilities and procedures for warranty contract disputes should be addressed.

6.2.13.3 Warranty Procurement

Procurement with a warranty provision introduces complexities not normally encountered. A fixed price is being paid for future guaranteed services. This creates problems in funding, in legal questions, and in assessing the realism of the price and the value of the warranty. The fact that several warranties are now in progress for several years and will be renewed, and others are just now being implemented, suggests strongly that these procurement difficulties can be overcome. However, some of these procurements involved intensive government effort to circumvent or

resolve the procurement problems. Changes in ASPR and decisions on funding should be made as required to allow for routine treatment of procuring under warranty.

6.2.13.4 Unverified Failures

The rate of unverified failures is quite large, both in military and commercial applications. The handling, shipping, and test costs that will be incurred by the military for such unverified failures sent back to the contractor can be significant. In the current Navy ASO/Lear Siegler warranty procurement, no additional cost is incurred to the Navy for unverified failures. The philosophy behind this approach is to involve the contractor directly in this problem so that he will institute design changes or recommend maintenance procedures that will reduce the unverified failure rate.[15] Also, this approach eliminates one significant area of possible dispute. While its purpose is laudable, most contractors would probably prefer specific authority to charge the military for unverified failure actions rather than attempt to estimate such costs in their warranty pricing.

6.2.13.5 Pipeline Time

An often expressed concern of contractor repair with warranty is the greater pipeline time such procedures will yield. When unit repair can be performed at the flight-line or organizational level, this may be true. However, for depot repair, we see no particular reason for any appreciable difference in pipeline times; and in some cases contractor repair can provide significant reductions. To reduce pipeline time, several contractual and procedural policies can be adopted.

One procedure commonly used by the airlines is to include a guaranteed contractor turnaround time with a penalty for failure to comply. Airlines use a spares-consignment approach, although a financial penalty is also possible. It would probably be to both parties' interest also to include some positive financial incentive for reduced turnaround time.

Another procedure is for the contractor to maintain a pool of rotable spares purchased by the military. Upon failure of a warranty item, the contractor is TWX'd by the using activity and a replenishment unit is shipped immediately to the using activity. After receipt and repair, the failed unit enters the rotable pool. This pipeline management approach is to be tested soon on A-7E avionics through a program known as CLAMP (Closed Loop Aeronautical Management Program).

6.2.13.6 Reduced Military Self-Sufficiency

There is no question that the military will suffer reduced self-sufficiency over the warranty period when contractor repair is the usual warranty procedure. We shall not attempt to explore the rationale of the need for such self-sufficiency but do note that in World War II, and in the Korean

[15] O. Markowitz - Aviation Supply Office (Navy) - Philadelphia, Pa., personal interview.

and Viet Nam conflicts, reliance was placed on elements of the civilian sector to perform operational maintenance functions on military equipment. The possibility of a strike, bankruptcy, or natural disaster that may afflict the contractor is a factor that must be considered.

Yet many current programs involving complex equipment depend heavily on the contractor for maintenance service, spare parts supply, and technical consultation. Certainly, the military using activity can contract for continual maintenance training of key military personnel by the manufacturer during the warranty period as a protection against sudden and complete loss of repair capability.

6.2.13.7 Data Requirements

Some of the current warranty programs in the military require fairly extensive data reporting and analysis procedures. This was partly due to the experimental pioneering nature of the long-term warranty provision that was involved. It is believed that both parties considered it necessary to collect enough data to determine the value of the warranty clauses. However, there are data requirements that are a direct result of warranty provisions and some others that should be considered.

If operating hours are included as a warranty basis, this type of data must be collected. Secondly, the contractor would be most interested in obtaining use information concerning failures so that he may have as much information as possible for instituting design improvements. Thirdly, if options for renewal exist, in order to develop an equitable price structure, the history of previous warranty practice would be pertinent.

6.2.13.8 Effects on Small Contractors

We believe that there is some element of truth to the statement that a long-term warranty provision may present possible risks to a small contractor that would discourage his entering the procurement competition. Certainly, large companies can better absorb the losses a warranty may cause if unanticipated reliability problems are encountered. Yet many large companies essentially consist of much smaller profit-centered organizations, making overall size perhaps less important than it first appears as regards decisions on bidding with a warranty provision. We must also note that many small avionics vendors do sell to airlines with warranty provisions much more comprehensive and penalty-structured than currently envisioned for military procurement.

6.2.13.9 Compliance Assurance

Use of warranties is recommended because of their ability to couple the vendor to the reliability-growth process of his product, providing profit incentives to maximize performance. The employment of performance bonds to assure warranty compliance is considered contrary to the spirit of the basic objective. It is recommended that the government act as a self-insurer with respect to assuring compliance with the warranty terms. Use of partial withholding of payments for warranty cost would reduce risk in the event of vendor non-compliance.

6.3 RECOMMENDATIONS

A number of recommendations are made in this section with regard to the future use of warranties for military avionics procurement.

6.3.1 Warranty Application

The expanded use of failure-free type warranty is recommended since it is the type most easily administered and is most compatible with existing supply and maintenance administration systems. MTBF, MTBUR, and cost-type guarantees should be considered only if improvements in current data and record-keeping procedures can be made. Warranty provisions should be applied only to fixed-price production and maintenance contracts.

6.3.2 Application Criteria

Criteria for selecting equipment that would be candidates for warranty coverage are enumerated as follows:

- The unit should be field-testable.
- Moderate to high initial support cost should be required.
- The unit should be readily transportable to permit returning to the vendor's plant.
- The unit should be generally self-contained and not highly dependent on outside units to perform major functions.
- The equipment maintenance concept and reliability characteristics should permit achieving readiness requirements in an economic manner.
- Specific knowledge concerning the unit application in terms of expected operating time and the use environment is necessary.
- The product must be sufficiently developed that reasonable estimates of the expected reliability and maintainability may be made.

6.3.3 Warranty Provisions

Warranty provisions for avionics systems should continue to exclude consequential damages. Warranty plans should be formulated to provide the fewest exclusions possible.

Unless the unit has a very low MTBF and high-cost transportation problems, it is best to have the vendor perform the repair at his plant. For the very-low-MTBF, complex units that would cause difficulty in shipment, vendors possibly can have personnel located at major Air Force centers.

Future warranty agreements should place constraints on the turnaround time the vendor must achieve on units returned for warranty repairs. The use of a consignment-spare penalty is suggested since such an arrangement will maintain adequate systems support to offset spares unavailability due to lagging turnaround time.

For warranty returns, the vendor should pay for shipping back to the user. Negotiations on who pays transportation charges to the vendor should be conducted for each application.

As a very general rule of thumb, the warranty period for a failure-free type warranty should be at least three years for new units. However, this figure may actually be increased or decreased if a detailed warranty cost analysis is performed to show that the optimum period is some other value. For older, proven systems, it is possible that this warranty period of three years may be reduced. Unless there is a great possibility of variation in operating hours, it is suggested that the warranty period be based on calendar time.

If the production run is not too extensive (one year), it is probably best to use a single warranty start time, such as average production delivery date. Therefore a single warranty end-date will be in force, rather than different warranty end-times for the units.

6.3.4 Warranty Procurement

On research and development projects, the government should state its intention of incorporating warranty provisions in the production contract. In this manner, the developing activity will design the product with the thought of warranty profit through good R&M characteristics.

A cost analysis such as that outlined in Chapter V should be performed for each proposed warranty application. Such an analysis investigates the relative cost in warranty and non-warranty situations and examines the cost of varying warranty time periods.

Warranty costs should be priced separately so that appropriate warranty and life-cycle cost analyses can be performed. This will also permit an evaluation of a design-to-cost requirement.

In the procurement contract with warranty, options should be provided for warranty renewal. However, it is probably best to leave the terms of such renewal open for negotiations based on the results of the initial warranty period.

6.3.5 Warranty Development

A warranty administration guideline should be developed to provide instructions to procurement, supply, and maintenance personnel with standard procedures and guidelines for securing and administering warranty contracts. A further part of this effort would be the formation of a set of standard terms and definitions applicable to the various warranty plans.

Efforts should be made to standardize the item and packaging warranty marking.

A training program should be considered for key procurement, supply, and maintenance personnel relative to the use of warranty procurements and administration.

Additional emphasis should be placed on the ability to provide in the field unambiguous go/no-go testing for warranty-covered items (non-warranty items would materially benefit from such an effort as well).

Service data systems and data-analysis products should be reviewed to determine how they can be modified to provide data products to support warranty administration. As an interim measure, warranty contracts should continue to require contractor-supplied data products to describe equipment performance.

DoD should promulgate a policy statement encouraging the expanded use of warranties. Final clarification should be provided in regard to warranty funding. The recommended course of action is that initial production systems be funded with production monies, but that warranties on subsequent replenishment buys and warranty renewals be funded with O&M funds.

A study snould be initiated to review and possibly eliminate or simplify some of the current R&M production testing and documentation requirements when warranty provisions are in effect.

6.3.6 Phase II Recommendations

This report constituted the completion of a Phase I effort directed toward an initial review cf warranty usage in the airline community and the military as well. As part of this effort, it was established that it is possible to determine the value of warranty on an economic basis. Chapter V of this report presents an initial effort towards evaluation of the costs associated with the failure-free type warranty plan. Although Phase I was a limited effort, it was found that data are available to support this type of analysis. It is thus concluded that a Phase II effort would be of value in providing a more in-depth analysis of alternate warranty plans, including a validation through the application of the models to a selected equipment development program. Details of the Phase II program were forwarded under separate cover to cognizant program monitors.

APPENDIX I

AIRLINE WARRANTY AGREEMENT

Exhibit I-1, presented on the following pages of this appendix, is an example of a comprehensive airline warranty agreement. It contains most of the provisions commonly used at present in the airline industry.

Exhibit I-1

A COMPREHENSIVE AIRLINE WARRANTY AGREEMENT

I. WARRANTY

1. The "Seller" warrants each system, component, and spare part furnished to the "Buyer"

   a. to be free from defects in material and workmanship, and manufactured in conformance with all applicable drawings, specifications and other written agreements;

   b. for a period of 36 months after delivery or 8000 operating hours, whichever shall first occur;

   c. to be merchantable and suitable for the particular purpose for which designed; provided that such products are installed, stored, maintained and used in accordance with any service and/or overhaul manuals, service bulletins and information letters furnished by Seller, and provided further, that such products are not modified in any manner by the Buyer, and that such products are not installed or used in any manner not reasonably anticipated by the above referenced instructions and specification requirements;

   d. that should any such defect develop in those products within the time specified above, where such products are installed, stored, maintained and used in accordance with Seller's written instructions, and are installed and used for the purpose for which designed in a manner reasonably anticipated by such instructions and by Seller's specification requirements, then Seller agrees to repair or correct such defects, or to exchange such defective part or product subject to the terms of Section II -- Warranty Administration.

2. Any product or part approved by seller for repair or exchange under this warranty will be repaired or exchanged without charge, but in no event shall seller be liable for any consequential or special damages due to said defects. The purchase and acceptance of seller products shall constitute a waiver by the buyer of any and all claims against seller for any such consequential or special damages. This warranty is intended as a product warranty only, and seller makes no warranty against latent defects in, or against injuries to property or persons resulting from, any use of such products.

3. The rights and remedies of Buyer and of Seller by this Warranty shall not be exclusive of other rights and remedies provided in law or equity, except to the extent that the warranties of Seller or the rights and remedies of Buyer are expressly limited by the provisions of this Warranty.

4. This Warranty shall inure to the benefit of the Buyer, its successors and assigns.

II. <u>WARRANTY ADMINISTRATION</u>

1. The Warranty set forth shall be administered as hereinafter provided.

2. All warranty repairs, corrections, and replacements will be at Seller's expense, provided that such defective part or product is delivered prepaid to Seller's designated maintenance and overhaul representative. The return by Seller to Buyer of corrected warranty equipment will be made at Seller's expense to Buyer's facility. Warranty claim determinations will be reasonably made based upon reports from Seller's regional representative, historical data logs, inspection, tests, findings during repair, and failure analysis. In the event that the defect or failure cannot be confirmed, then Buyer shall bear the expense of shipment to Seller's factory and return shipment to Buyer's facility, plus the cost of testing the returned part or product.

3. Systems, LRU's, or parts presented for repair will be accompanied by the following documentation:

   a. A written request for repair under Seller's warranty.

   b. Nomenclature, serial number and part number of the LRU.

   c. Reason for removal, including a brief description of failure data.

   d. Buyer's name, aircraft registration number, and location of facility at which the unit or assembly was removed.

   e. Location to which unit or assembly should be returned.

4. If it is reasonably determined in the joint judgment of the Buyer and Seller that it is not practical to return the unit or assembly to Seller's plant for repair, Seller shall (a) effect repair or correction at Buyer's location, or (b) repair shall be effected at Seller's field repair location, or (c) Buyer shall effect repair at his facility subject to the terms hereof.

5. If Buyer elects to utilize option 4 (c), the following shall apply:

   a. Buyer will make a conscientious effort to establish the cause of failure, extent of failure and the responsibility of the failure. This information, along with part number, serial number and functional test data (where applicable), will be submitted to Seller with each claim.

   b. In the event that Seller is responsible for all or part of the failure, Buyer is authorized to make such repair as is required and invoice Seller for its just share of responsibility under the terms of this Agreement.

   c. Warranty repairs consuming less than three (3) hours shall not be considered a part of this Agreement unless a repetitive type failure problem occurs. Scheduled "Unit Bench Test" and/or "Shop Checks" shall not be considered a part of this Agreement. For purposes of this Warranty, a "repetitive failure" shall be one which occurs two or more times in the same unit within a sixty (60) day period.

   d. Units repaired under this Warranty shall be on an "Inspect and repair as necessary" basis.

   e. If a unit has a malfunction and is overhauled by Buyer within the warranty period at Buyer's option, Seller shall not be responsible for any portion of the labor expended other than that portion directly related to that malfunction which caused removal of the unit from its place of installation.

   f. "Repair" is defined as the minimum labor necessary to return a unit to a serviceable condition.

Exhibit I-1 (continued)

g. A written "WARRANTY REPAIR CLAIM" (3 copies each) shall be submitted to Seller (Attention: Manager, Product Support) requesting a credit to the Buyer's account equal to the number of direct labor hours expended multiplied by an hourly rate established as set forth in paragraph h. hereof.

h. For repair of "in-warranty" units pursuant to the terms hereof, Buyer shall be reimbursed at a negotiated annual hourly rate per man-hour of repair and test, with no overtime provision.

i. For any single repair incident, the maximum number of man-hours for which repair and test reimbursement will be provided is six (6) man-hours.

j. After repair of each unit by Buyer, the remainder of the original warranty will apply, except for ensuing failures resulting from Buyer workmanship.

k. Reimbursement for warranty repairs shall be made by credit memo every sixty (60) days.

l. Buyer shall summarize, month by month, for reimbursement purposes, all repairs performed during the period of validity of this Agreement.

m. All values shown in claims must be in U. S. dollars.

n. Seller reserves the right to:

   1. Assist in the verification of findings, and to periodically witness the repair of units.

   2. Review each claim in detail, including request for additional data, prior to final acceptance.

o. Reimbursement of failed components.

   1. Replacement will be on exchange basis, at no cost to Buyer. A copy of the warranty claim should accompany the failed components. This replacement should be done simultaneously with the warranty claim whenever possible.

   2. Products deemed defective by Buyer must be returned to Seller freight prepaid. After repair or replacement, Seller shall return such products freight prepaid.

Exhibit I-1 (continued)

III. GUARANTEES

1. Reliability Guarantees

Seller will guarantee the LRU's as shown below. The MTBF is applicable to the average MTBF of all Seller's LRU's in operation by Buyer throughout the applicable period.

Guarantees

On Aircraft Labor	x man-hour/flt. hour
Off Aircraft Labor	x man-hour/flt. hour
Material Maintenance	x dollars/flt. hour
MTBF - 0-24 mos.	x hrs, 80% growth curve
25-60 mos.	x hrs, 80% growth curve

Administration of cost guarantee to be in accordance with ATA Spec. 200, Chapter 5, plus x percent deadband over guarantee and subject to normal escalation which shall not exceed x percent per year.

2. As a prerequisite to participation in this program, Buyer will provide system failure data from the date Buyer's first certificated aircraft enters revenue service. The data will be of sufficient detail to determine MTBF and any additional spares required.

3. Spares provisioning will be determined by Buyer, and will be based on the MTBF guarantees set forth in Paragraph 1, as modified by other program factors determined by Buyer.

4. Support is to be based on the data provided by Buyer in accordance with Paragraph 2, and such data will be used to compute any additional spares required. Such spares will be made available on a no-charge consignment basis.

5. MTBF measurements will be based on a monthly measurement corresponding to a three (3) month moving average. Seller's obligations under the MTBF guarantee program shall terminate when the final MTBF guarantees stated in the table set forth in Paragraph 1, are achieved over twelve (12) consecutive monthly measurements commencing no earlier than the 25th month after introduction of Buyer's aircraft into revenue service.

6. The specific provisions for measuring the MTBF are as hereinafter set forth:

   a. <u>Calculation of MTBF</u>

      The LRU MTBF is defined as the total number of LRU operating hours in a specified period divided by the total number of confirmed failures in the specified period.

   b. <u>Definition of Failure</u>

      The following failure definitions and conditions shall apply:

      (i) Confirmed failure - An LRU removed from an aircraft for suspected failure shall be deemed a confirmed failure when, upon being subjected to test in the condition removed from aircraft, it is unable to pass the test for that LRU specified by Seller's Overhaul Manual supplied to Buyer or other mutually agreeable test procedure. The specified test must be comparable in scope to Seller's acceptance test for production equipment. Tests may be performed in Buyer's facilities or those of its FAA approved designee or those of Seller.

         aa. Failure caused by improper repair, service, handling or overhaul by Buyer personnel or Buyer's designated facility other than Seller is not a confirmed failure for purposes of MTBF determination.

      (ii) Irrelevant Failure - Irrelevant failures shall not be counted in the MTBF determination. Irrelevant failures are defined as follows:

         aa. A failure caused by a condition external to the system, such as improperly supplied power, improper interconnecting wiring, or improper operation of the system.

         bb. The failure is a dependent (secondary) failure resulting from an independent (primary) failure within the same LRU provided that the independent (primary) failure is specified. A dependent failure occuring in a separate LRU from the LRU in which the primary confirmed failure occurred shall be considered a failure.

(iii) Minor Failure - Minor failures shall not count in the MTBF determination. The following are considered minor failures:

aa. Certain part failures which do not in any way affect the normal functions and performance of the system and which can be repaired without removal of an LRU from the aircraft and which do not cause aircraft delay.

(iv) Additional Requirements - At all times while in Buyer's possession the equipment shall be subjected to an environment within specification requirements. Failures which occur as a result of an exposure to an environment in excess of that specified will not count in the MTBF determination. Failures resulting from accident, or improper maintenance shall not count in the MTBF determination. Operation and maintenance procedures shall be in accordance with the aircraft operating and maintenance manuals and with Seller's maintenance and overhaul manuals furnished to Buyer. In the case of conflict between aircraft manuals and Seller's manuals, the Seller's manuals will prevail.

7. a. In the event the average MTBF calculated for any LRU's in operation in a calculation period is less than the guaranteed MTBF, Seller shall consign additional spare units at no charge based on the following formula:

$$n = NS \frac{G-A}{G}$$

n - Maximum number of additional spare LRU's to be consigned to Buyer under MTBF guarantee program. This number shall be rounded to the nearest whole number, but not less than 1, and shall not exceed 100% of spare LRU's procured as of the date of MTBF calculation.

Ns - Total number of spare LRU's procured by Buyer as of the date of MTBF calculation.

G - Guaranteed MTBF for the LRU.

A - Actual calculated MTBF for the LRU.

b. Failure classification will be mutually agreeable to Seller and Buyer. If no agreement can be reached, then failed unit shall be subject to failure analysis prior to classification.

c. If additional consignment units are required to be furnished by Seller to Buyer hereunder, Seller shall ship such units to Buyer as soon as reasonably possible, but no longer than 60 days after completion of the MTBF calculations by Buyer. Buyer shall notify Seller if the indicated number of consignment units exceeds Buyer's requirements, in which case, Seller shall be obligated to supply only that quantity required by Buyer.

8. Return of Consignment Units

Any LRU's consigned under the provisions of Paragraph 7, shall be shipped to Seller as soon as possible, but no later than 60 days after an MTBF calculation in which the system meets or exceeds the previous internal MTBF calculation.

IV MANUALS, DATA, TECHNICAL ASSISTANCE

1. Seller shall furnish, at no cost to Buyer, a reasonable quantity of sets of all operating, maintenance, overhaul and parts manuals conforming to ATA Spec 100 required for the installation and maintenance of the units. Service bulletins and such revisions to the above manuals and data as may be necessary to reflect revisions in operating, maintenance, or installation procedures shall be furnished promptly.

2. Seller shall provide the minimum engineering information and data necessary for the installation, service and repair of subject equipment by Buyer.

V PATENT PROTECTION

Seller agrees to indemnify and hold Buyer harmless from and against any and all loss, cost, damage, expense and liability (including reasonable attorney's fees) resulting from the infringement or alleged infringement of any United States or foreign patent or patent right by reason of the manufacture, use, sale or resale of the items sold by Seller to Buyer hereunder; provided, however, that this indemnification provision shall not apply and no right to indemnification hereunder shall arise with respect to any claim, loss, cost,

damage, expense or liability unless Buyer gives Seller written notice of any matter with respect to which indemnification will be sought hereunder promptly upon the receipt or obtaining of knowledge of such matter by Buyer. In the event any claim is asserted or threatened, as to which Buyer will seek indemnification hereunder Seller shall have the absolute right to defend against, settle, compromise or otherwise dispose of said claim, including but without limitation thereto, the right to contest or litigate the same through counsel of its own choosing, and Buyer agrees to cooperate with Seller fully with respect thereto at no cost or expense to Buyer.

VI SPARE PARTS, SERVICE AND TRAINING

1. Seller will make available to Buyer spare parts, accessory equipment and/or components which are now, or will hereafter, be manufactured either by Seller or by others to Seller's design or order, and which are not readily available on the commercial market, in adequate quantities to meet Buyer's needs for repairs and replacements with respect to all products purchased. Components will be sold and delivered with reasonable promptness upon receipt by Seller of Buyer's order at Seller's prices prevailing at the time of receipt of each such order. Such prices will be reasonable and will be firm for ninety (90) day periods following the issuance of respective price quote.

2. Seller agrees that the spare parts which it has the obligation to make available to Buyer will be available at its factory or at other suitable designated points. Delivery lead time required for such parts shall in no event exceed one hundred twenty (120) days.

3. Seller will provide ATA-100 type operating, maintenance (including exploded parts view) and spare parts manual to all Buyer's of Seller's equipment. Such manuals will be registered to Buyer and Seller will maintain all changes or additions to each specific manual. In addition, Seller will supply Buyer with a current spare parts price list.

4. Seller will maintain an FAA approved overhaul station at its facility. Such facility will be staffed with technically qualified service representatives fully competent to accomplish repair and/or modification of Seller's products.

5. Seller will provide training for Buyer's maintenance personnel in the operation, maintenance and overhaul of products at its plant during scheduled periods of time to be mutually determined by Buyer and Seller. Seller will also engage in field support activities at all domestic Buyer's facilities as required for sufficient field training and product support. Seller will require no payment for reasonable amounts of such training service.

VII PRODUCT SUPPORT

A. General Terms:

1. Seller shall furnish all the elements of Product Support outlined in this Agreement at no cost to Buyer, unless otherwise specified herein.

2. Seller shall comply with ATA Specifications 100, 101, 200 and 300.

3. Seller shall have, or agree to obtain, adequate facilities and qualified personnel to provide Buyer the proper support of its products and equipment as long as at least five (5) aircraft equipped with this system are in regularly scheduled operation.

4. Seller shall require of its lower-tier suppliers, to the extent applicable, the same product support assurances granted Buyer. In the event such lower-tier suppliers fail to comply, the Seller will then assume and fulfill the necessary obligations at no additional cost to Buyer.

B. Spare Parts Provisioning:

1. Seller shall supply initial spare parts recommendation data and revision service to Buyer at no additional charge.

2. Seller shall, at no charge, provide continuous revision service for all provisioning data until such services are discontinued by mutual consent.

3. Seller shall provide, without charge, qualified personnel to assist Buyer in the initial provisioning of the system, if so requested by Buyer.

C. Spare Parts Marketing and Inventory:

1. Seller shall maintain a stock of insurance spare parts, in sufficient range and quantity, as to meet Buyer's normal recurring and emergency operating requirements. Such material shall be maintained in a manner and location sufficient to provide for delivery to Buyer within thirty (30) days of the receipt of a routine purchase order or twenty-four (24) hours on an emergency basis.

2. Seller warrants that all spare parts purchased from Seller by Buyer shall, at the time of delivery, be in a proper configuration for installation on Buyer's aircraft. If Seller ships incorrect spare parts to Buyer, Seller shall make immediate no charge correction and bear all costs of transportation related to the return and reshipment of such material.

3. Seller shall permit Buyer to fabricate, or permit others to fabricate, spare parts in the following events:

   a. If Seller becomes bankrupt or insolvent.

   b. If Seller suspends manufacture of its products or cannot at any time produce at a reasonable price.

   c. If Seller fails to fulfill its obligations under this Agreement.

   d. At any time that such spare parts are needed to effect emergency repair and Buyer can obtain such items from another source sooner than Seller's quoted emergency delivery schedule. In such cases, the warranty for any component or part shall lie with the Buyer or supplier of such component or part.

4. Seller shall promptly provide price and delivery quotations to Buyer upon request and such reply will be by the same media through which the request was transmitted. Routine mail request shall be replied to within ten (10) calendar days after receipt. Telegraphic requests shall be answered by wire within twenty-four (24) hours after receipt. Telephone requests shall be answered by phone within eight (8) hours if the information is not immediately available.

5. Seller shall accept purchase orders from Buyer for any spare parts pertaining to Seller's products and shall promptly act upon such purchase orders. Seller shall further acknowledge each such purchase order to Buyer in writing within ten (10) calendar days from the date of receipt thereof. Seller's acknowledgment shall contain delivery information, notice of changes, price, and such other information as may be required for the specific transaction.

D. Spares Pricing:

1. Seller's spare parts prices shall be fair and reasonable and set forth in a formal price list. Such advertised prices shall remain firm for a period of one (1) year from issuance, at which time a revised price list may be issued. This revised price list must be issued ninety (90) days prior to the effective date to Buyer.

E. Packaging:

1. Seller shall package all spare parts sold to Buyer in accordance with ATA Specification 300.

F. Order Administration:

1. Seller shall establish qualified personnel within its organization to regularly administer orders, inquiries, and technical services required by Buyer with respect to Seller's products, spare parts and data.

2. Seller shall provide a point of contact for emergency ordering and technical inquiries on a twenty-four (24) hour day, seven (7) day a week basis.

APPENDIX II

FAILURE-FREE WARRANTY PROVISIONS

The failure-free warranty provisions shown as Exhibit II-1 were developed by Lear Siegler, Instrument Division, being derived from their current contracts from Aviation Supply Office and U.S. Air Force contracts. In setting forth these provisions, they have made the following comments:

1. Since all products and their specifications have individually distinctive characteristics, this will require some minor modifications and/or additions to these clauses. The clauses should be used only as a standard starting point. They are not intended for use in a pure "cook book" fill-in-the-blanks approach.

2. The following FFW clauses are a combination of the most workable ones from both of the original Navy and the Air Force FFW contracts.

3. There are several individually numbered characteristics which normally vary from product to product that must be identified for each product considered as a candidate for the application of the FFW procurement concept. If the Contracting Officer and/or his technical counterpart will obtain the information identified in these individually numbered characteristics and write them in the numbered blanks, it will be a relatively simple process to then fill in the correspondingly numbered blanks marked throughout the proposed warranty provisions.

4. Since these warranty provisions come directly from two currently existing contracts, it is assumed that they have passed the legal reviews of both the Navy and the Air Force.

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INSTRUCTIONS FOR APPLYING EXTENDED TERM/FAILURE FREE WARRANTY

These warranty provisions are divided into four (4) major parts.

PART I - Statement of Contractor Warranty

PART II - Contractor Obligations

PART III - Government Obligations

PART IV - Miscellaneous

The key individual characteristics listed below constitute all required information to fill in the blanks of the attached model provisions.

First develop a list showing your selected values/nomenclature, etc., to be used for the characteristics items listed below.

Then insert value nomenclature for the item corresponding to the number (N) in each of the correspondingly (N) numbered blank spaces.

(N) = NUMBER KEY FOR FILLING THE BLANKS OF THE INDIVIDUAL CHARACTERISTICS/ FFW WARRANTY

1. Name of the Unit ____________

2. Contractor's Name, Logo or Initials ____________

3. Contractor's Model Number ____________

4. Contractor's Part Number ____________

5. Controlling Field/Depot Test Spec or T.O. ____________

6. Quantity of Operating Hours Warranted - (Warranty max. duration in unit operating hours, usually only 80/90% of anticipated average unit flight program, plus ground operating time for calender warranty period.) ____________

7. Quantity of Years Warranted - (Warranty max. duration in years - usually 10/20% longer than that period required to experience average unit flight program. ____________

Exhibit II-1

INSTRUCTIONS FOR APPLYING EXTENDED TERM/FAILURE FREE WARRANTY

8. Quantity of Days Warranted (Set same as 7 above) ____________

9. Aircraft Type Designation(s) using Warranted Unit ____________

10. System Designation using Warranted Unit ____________

11. Field/Depot Test Set Designation ____________

12. Using Service Test Record Tag or Form # ____________

13. Federal Stock # of Shipping Container ____________

14. Contractor's Authorized Warranty Repair Station ____________

15. Minimum Number Days - No Incentive "Turn-around" ____________

16. Maximum Number Days - No Penalty "Turn-around" ____________

17. 12 Months Less Than Total Warranty Term in years/days ____________

18. Total Quantity of Units Under Warranty ____________

19. ACO or PCO & Symbol ____________

20. Using Service Operational, Logistic and/or Maintenance Data System Identifier ____________

21. A fixed % usually 150% or more of most or all the field level acceptance test values. Those values must be set to allow some degridation from "as new" mfg or overhauled/repaired units, but when operating to their expanded limits must still furnish acceptable input to the other interfacing boxes of the system ____________

Exhibit II-1 (continued)

FAILURE FREE WARRANTY PROVISIONS
FOR
9 10 SYSTEMS
1 2 MODEL 3

Part I - Statement of Contractor Warranty

1. Notwithstanding Government inspection and acceptance of supplies and services furnished under this contract or any provision of this contract concerning the conclusiveness thereof, the contractor warrants that each 1 2 Model 3, Pn 4, FSN ________, unit furnished under this contract will be free from defects in material and workmanship and will operate within 2% of the single value tolerance requirements for the unit as specified T.O. 5 for the first 6 hours or 7 years 8 days after induction, whichever first occurs, when properly installed in the 9 aircraft as part of the 10 System.

2. Any such unit furnished under this contract which fails within the warranty period and which is returned to contractor's plant or designated repair facility, at the expense of the Government, shall be repaired, or replaced, at contractor's sole option, at no change in contract price so as to operate within the test limits of 5 as specified in Paragraph 1 above. The unit as replaced shall be delivered to the Government in the shipping container specified by this contract, FOB contractor's plant or repair facility, freight not allowed.

3. Subject to the provisions of Part IV, Paragraphs 2, 3, and 6, and except for losses which would not have occurred but for the fault or negligence of the Contractor, the Contractor shall not be obligated to repair or replace any such unit warranted here under which is lost or damaged by reason of transportation, handling, fire, explosion, submersion, flood, aircraft crash, or enemy combat action, unless such loss or damage occurs on premises owned or controlled by the Contractor.

4. At the Government's option, units declared lost or stricken may be replaced for a consideration paid to the Contractor with a non-warranted unit and received transferred credit of remaining warranty coverage from the replaced unit in the amount mutually agreed upon by the Contractor and the Government.

5. Except as provided by the clause entitled Inspection and Acceptance, contractor's obligations, and the Government's remedies, for repair and replacement, are solely and exclusively as stated herein. In no event shall the contractor be liable for special consequential or incidental damages.

Part II - Contractor Obligations

1. All contractor initiated reliability/maintainability ECP's for the unit shall be covered per normal ANA Bulletin 445 procedures. See also Part III, Paragraph 3.

2. The contractor shall cause a suitable and prominent display of the following information or its equivalent in addition to the standard identification

Exhibit II-1 (continued)

plate, to be placed on the surface (s) of the unit to insure reasonable visibility when installed and/or removed.

1. Warranted product.

2. For (6) ETI hours of (7) years ((8) days) from the date of initial shipment, whichever first occurs.

3. If this unit fails within the warranty period, the following action must be taken by the using activity:

a. Verify the failure on the appropriate Test Set, ___(11)___ per ___(5)___

b. Record failure circumstance data and line tester findings on ___(12)___ tag or equivalent.

c. Package in original container, FSN ___(13)___ or equivalent and return both the unit and failure circumstance data to ___(14)___, ___.

Within 120 days after receipt of award, the contractor shall submit to the Government for approval the proposed wording, content and replacement of this information. Material suitability and method (s) used to apply it to the unit shall also be submitted at this time for Government approval.

3. Turn-around Time - Serviced (1)

The turn-around time for units input for servicing under the Failure Free Warranty provisions of the contract shall average (15) to (16) days.

Further, on the (15) to (16) day turn-around time, an incentive/penalty shall be applied as follows:

(1) A contract average turn-around time (date received to date shipped by contractor) shall be developed and included as part of the data requirements as in FFW report. See Part II, Para. 6 (A) "FFW Warranted Products System Status Report".

(2) ___(17)___ months after the beginning of the warranty period this average shall:

(a) Be determined as $\pm$, i.e., more than (16) days or less than (15) days.

(b) The difference shall be multiplied by the number of units experienced to that date and then divided by the quantity of ___I___ under warranty (18)

(c) The Warranty period for each warranted unit shall then be:

Shortened (incentive), or
Lengthened (penalty) by that amount depending upon whether the average determined in 2a above is less than (15) days or more than (16) days.

Exhibit II-1 (continued)

If the resulting average is between 15 days and 16 days, no change shall be made.

4. The contractor shall maintain records by serial number for each unit under warranty. These records shall include, but not necessarily be limited to date shipped, date failed, date received, date reshipped, with corresponding elapsed time indicator readings as well as the warranty period remaining to be used on each unit. These records shall be made available to the Government upon request.

5. The contractor shall place these warranty provisions in all Technical Manuals that provide coverage for this ____1____.

6. Data Requirements

The contractor shall agree that in conjunction with the warranty to be supplied hereunder, the contractor will establish and maintain a data system capable of assimilating the data inputs required to provide the following data products for the ____1____. These data products shall be processed and submitted quarterly to consist of, but not necessarily be limited to the follow:

(A) FFW Warranted Products System Status Report.

This report shall present the print-out of a comprehensive overview of program status and shall show: (1) Warranty days and hours, shipped, used, and remaining. (2) All four (4) pipeline quantities of units shipped, returned, in the field, in aircraft, at __2__ and stricken. (3) Average aircraft and __1__ utilization rates ground-to-air operating ratios. (4) Mean-Time-Between-Return and Mean-Time-Between-Failure.

(B) A narrative synopsis of FFW-Warranted Products System Status Report.

(C) FFW - Unit Status Summary-MTTR-MTTF Report:

This report will show: (1) Each FFW unit by Serial Number. (2) Elapsed clock time and cycle completion date for each ship-to-return cycle completed by each unit. (3) Entries appearing on the report for the first time are to be highlighted. (4) The latest known status of each unit is to be shown along with the action date. (5) A two-part summary shall appear at the end of this report to show: (a) Incremental Mean-Time-To-Return and Mean-Time-To-Failure by cycle by month for each of the preceding twelve months. (b) MTTR and MTTF figures to date by cycle for each of the preceding twelve months.

(D) FFW Units Presumed Lost Report.

This report shall: (1) List those units presumed lost aboard stricken aircraft. (2) Show serial number and installation

Exhibit II-1 (continued)

date, aircraft type, bureau number and strike date. (3) Display hours accumulated by both the aircraft and the (4) between the installation and strike dates be displayed. These data provide the basis for determining the amount of warranty to be carried by replacement units.

(E) FFW Unit - Low Activity Report:

This report shall display two lists: (1) All units whose latest record indicates shipment from ____(2)____ to the Navy and for which there has been no report for a period of at least 90 days. (2) All units whose latest record indicates installation in an aircraft for which there has been no reported activity for at least 60 days. Unit serial numbers and the number of days inactive for each unit shall appear in these lists.

Part III - Government Oblication

1. The Government shall, to the extent possible:

a. Test all units on applicable ____(11)____ test sets, per ____(5)____ at point of removal prior to return to contractor.

b. Furnish maximum failure circumstance data and test readings, correctly recorded on ____(12)____ tag or equivalent.

c. Utilize the same type and closed condition of container and packaging for all shipments or transporting of the units whether new or in need of repairs as used by the supplier to originally ship the unit.

d. Return each unit within sixty (60) days to the failure occurrence including the furnishing of recorded failure circumstanced data on ____(12)____ form or equivalent. However, in the event a unit is not returned within said sixty (60) day period or the failure circumstance data is not furnished, the warranty shall remain in effect as to such unit.

2. The Government will be responsible for maintaining an adequate supply of containers or the equivalent thereof for reshipment of the units to and from their destinations for the life of the warranty.

3. In recognition of the high contractor motivation for total cost control effected through the incentive feature of these warranty provisions, the Government agrees that all no cost ECP's submitted in accordance with ANA 445 to improve reliability and maintainability for the unit will receive special expeditious processing through the approved cycle.

Notwithstanding this special processing, any such ECP shall automatically stand as officially approved by the Government 30 days after receipt by the ____(19)____ symbol ____(19)____, unless the contractor has received written notification of its disapproval from the Government prior to that date.

4. The Government will be responsible for providing all (20) and other service type data to the contractor. Failure to supply essential data elements shall automatically relieve the contractor of his obligation to maintain the Data System Reports required by Part II, Item 6, until such time and the input data is supplied by the Government.

Exhibit II-1 (continued)

Part IV - Miscellaneous

1. Upon the receipt of the returned unit at contractor's plant or repair facility, the resident DCASD Quality Assurance Representative shall determine whether repair is required under this warranty.

2. Disposition: (Applicable only to Part I, Para. 3 above) Each unit returned under this contract for warranty support that, upon examination at the supplier's facility, is not considered to be economically repairable by the Government shall be declared non-repairable and disposed of by the contractor as directed by the __(19)__.

   a. The contractor shall have the right to assert charges for any reasonable services performed by the contractor as directed by the __(19)__ in connection with the disposition of Government property herein above described. Any materials required to be furnished by the contractor in connection with shipment of such Government property shall be regarded as Direct Materials for which the contractor shall be entitled to reimbursement.

   b. In no event will the contractor be allowed to retain the dispositioned unit unless he reimburses the Government for its value to him.

3. If the Government directs the repair of a unit damaged by one of the causes set forth in Part I, Para. 3, an equitable adjustment in contract price will be negotiated for such repair.

4. Transfer of Warranty Credit

   If, within 36 months after date of initial shipment under contract (induction), an article is determined to be out of warranty for any of the following conditions: Unauthorized Repair/Opening, Obvious Damage, Lost Stricken*, Dispositioned, "O" Activity*; the unit may be returned to warranty or have the remaining warranty credited and/or transferred to a like unit by applying one of the following options:

   *NOTE 1: Criteria for Lost/Stricken and "O" Activity Units shall be the appearance of the same FFW unit serial number on any two (2) consecutive quarterly Presumed Lost & Stricken and/or Low Activity Report.

   Option 1

   The unit returned to the Contractor and the Contractor, at his sole discretion, electing to repair the unit as if the said unit had failed for causes covered by warranty.

   Option 2

   The unit returned to the Contractor with authorization from the Government to repair and charge the Government for all repair costs except those which would have been incurred and covered by the warranty.

   Option 3

   The Government providing failed replacement unit either new or existing

Exhibit II-1 (continued)

non-FFW unit, paying the Contractor for the initial induction/repair at the contract price and directing the Contractor to transfer ** the remaining warranty to the replaced unit.

Option 4

By mutual consent of both Government and Contractor: transfer** remaining warranty from damaged-dispositioned and/or lost and stricken units to other active FFW units under this contract.

It shall be incumbent on the Contractor to notify the Government of all units requiring any of these actions within 30 days of receipt of the unit or contract report showing units with one or more of these conditions.

**Note 2: a) If Government authorization is received by the Contractor within 60 days after initial notification by the Contractor to the Government, the warranty shall transfer on a pro-rata basis from the date of the second report.

b) If Government authorization is not received within 60 days after notification from the Contractor, the warranty shall transfer from the date the authorization is received or mutual consent achieved.

c) In no event shall any transfer or other adjustment be made after 80% of the calender warranty period has been used. Further, the calender warranty expiration date of the replacement unit shall be the same as for the original replaced unit.

Lost and stricken units which are subsequently found and returned to the inventory shall be returned to warranty and the Contractor repair for the full warranty period that was transferred and/or credited to some other warranted units.

5. All material removed from any unit repaired by the contractor or any unit replaced pursuant to this warranty shall become contractor's property except as provided in the disposition provisions hereof.

6. The Government shall not provide new (i.e. additional facilities, tooling or equipments of any type for contractor performance under the warranty unless it is specifically negotiated at the time of basic contract award.

7. If the Contracting Office determines that a deficiency** exists in any of the units accepted by the Government under this contract, he shall promptly notify the contractor of the deficiency, in writing, within 45 days after discovery of the deficiency. If the contractor independently discovers a deficiency in accepted supplies, he shall promptly notify the Contracting Officer in writing. Upon discovery or notification of a deficiency, the contractor shall promptly submit to the Contracting Officer his recommendations for corrective actions, together with supporting information in sufficient detail for the Contracting Officer to determine what corrective action, if any, should be undertaken.

** Defined (for the purpose of this paragraph) as failure of a unit to meet (a) the requirements of ___5___

Exhibit II-1 (concluded)

APPENDIX III

A LIFE-CYCLE COST MODEL FOR EVALUATING A FAILURE-FREE WARRANTY PROVISION

1. INTRODUCTION

In this appendix, we develop a model for evaluating the life-cycle costs associated with a failure-free warranty provision under which the contractor or vendor assumes the responsibility for repairing or replacing a failed item. This warranty provision applies for a specified time period (calendar time or operating hours or cycles). To be effective, the provision will usually apply to all types of failures except those due to gross abuse or mishandling, combat damage, aircraft crash, or similar extreme operational conditions.

Since the supplier is responsible for most item repairs or replacements throughout the warranty period, he generally will attempt to estimate the costs associated with the warranty obligation and include them in the unit price. The purchaser is also interested in evaluating warranty costs in order to determine (1) whether or not a failure-free warranty provision is cost-effective, (2) the optimum warranty period, and (3) the realism of supplier-proposed costs associated with the warranty.

We consider here a model for evaluating the life-cycle costs associated with a failure-free warranty provision in the procurement of defense avionic equipment.[1] The model is developed to be applicable during the development and preproduction stage, when consideration of a warranty provision for the production contract is most important.

The model includes only costs that may vary with warranty terms and conditions. Thus the costs associated with operating the equipment are not considered. In addition, we consider only the major cost elements -- for example, average cost to repair the item at a military depot. Such details as inflation rates are excluded. Submodels to quantify some of the cost elements included herein and techniques to account for inflation rates, etc., can be obtained from any of a number of DoD and military publications on life-cycle costing.

[1]The restriction to avionic equipment is imposed to avoid the complications associated with items that exhibit a wear-out failure mechanism.

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2. PREMISES AND ASSUMPTIONS

The major premises and assumptions under which the model is developed are as follows:

- The units are sealed or are of such complexity that base maintenance involves only removal/replacement and failure-verification tests. Repair is performed at depots or contractor facilities; therefore, base sparing is at the unit level.
- The failure distribution of the avionic equipment is assumed to be exponential with the failure rate, λ.
- At the initial procurement stage, the value of λ is not known, but data on similar equipment and application of reliability prediction and evaluation techniques will yield an expected distribution of λ, which, for mathematical simplicity, is assumed to be discrete (p_i, λ_i). For a no-warranty procurement, if the observed failure rate is poor, the user will request a modification to improve reliability if the cost of such modification is less than the expected savings in repair costs. For a warranty procurement, if the observed failure rate is poor, the contractor will attempt to introduce a "no additional cost" modification to improve reliability if the cost of such modification is less than the expected savings in warranty-repair costs.
- If a modification is desirable, the time at which it can be introduced, T_m, is governed by a two-parameter exponential distribution,

$$f(T_m) = de^{-d(T_m - T_\alpha)}, \quad T_m > T_\alpha.$$

- The expected reliability improvement due to a modification is a function of the ratio of actual failure rate to specified failure rate.
- In establishing a unit price under warranty, the contractor will estimate his risks (including the possibility of having to introduce a modification) and include the cost of such risks in his price.
- The cost of a modification is directly related to the amount of reliability improvement. Because of the sole-source environment associated with a modification without warranty, the price the user pays for modification without a warranty may be greater than the price increment charged under a competitive procurement when a warranty provision exists.
- Although a warranty provision will have life-cycle-cost implications after the warranty period expires, we consider life-cycle costs only over the warranty period. The primary reason for doing so is that a contractual warranty provision may have options for renewal. The decision on accepting the option and the terms of the renewed warranty agreement will naturally be made after cost and failure data

accrued during the initial warranty period are evaluated. It is therefore believed that including this type of decision in the model would not be productive.

However, since the warranty period may be less than the equipment lifetime, we will amortize all user investment dollars (initial and modification cost) on a straight-line basis in order to provide a fair comparison of costs associated with varying warranty periods.

3. THE GENERIC LIFE-CYCLE COST MODEL

We now introduce a generic life-cycle cost model to indicate the scope of detail we are considering and to develop some basic concepts and notation.

The three major cost elements considered are the initial acquisition costs, the direct costs associated with a failure, and the indirect costs associated with maintenance support. The generic model will then take the following simple form:

Life-Cycle Costs over (O,T) = Number of units bought × price per unit
+ expected number of failures (O,T)
× cost per failure
+ maintenance support costs (O,T)

As a notational convenience, we reserve the superscript k exclusively for distinguishing between a non-warranty situation (k = 0) and a warranty situation (k = 1). Thus if C_x is used to denote a specific cost, C_x^k will be used to indicate that this cost may depend on the existence of a warranty provision -- the cost without warranty denoted by C_x^0 and with a warranty denoted by C_x^1.

We now can write the generic model as follows:

$$LCC^k_{T_w} = N^k C^k_p + N_o \bar{\lambda}^k H_o T_w C^k_F + C^k_s \qquad (1)$$

where

$LCC^k_{T_w}$ = life-cycle costs over (0, T_w) associated with warranty evaluation

N^k = number of units purchased

C^k_p = purchase price per unit

N_o = number of operational units

$\bar{\lambda}^k$ = average failure rate over (0, T_w)

H_o = operating hours per month per operational unit

T_w = warranty period in months

C_F^k = direct user cost per failure

C_M^k = maintenance support costs

As a further notational convention, the subscripts U and C will be used to differentiate between user and contractor. For example, if C_G represents shipping costs per failure, C_{GU}^1 represents shipping costs to the user when a warranty provision exists and C_{GC}^1 is the corresponding shipping costs to the contractor.

4. USER COSTS PER FAILED UNIT -- C_{FU}^k

If a unit fails, the user incurs costs with or without warranty. These include on-aircraft removal/replacement costs, test and repair costs, shipping cost, and material cost. Thus

$$C_{FU}^k = H_{LU}^k C_{LU}^k + C_{GU}^k + C_{EU}^k \tag{2}$$

where

C_{FU}^k = user direct maintenance cost per failure

H_{LU}^k = total user labor hours per failure

C_{LU}^k = average user labor rate per failure

C_{GU}^k = average user shipping costs per failure

C_{EU}^k = average user material cost per failure

5. CONTRACTOR COST PER FAILED UNIT -- C_{FC}^k

If a warranty exists, the contractor incurs costs associated with repair of failed units. It is assumed that without warranty, no costs are incurred by the contractor. Hence,

$$C_{FC}^k = \begin{cases} 0 & , k = 0 \\ H_{LC}^1 C_{LC}^1 + C_{GC}^1 + C_{EC}^1 & , k = 1 \end{cases} \tag{3}$$

where

C^k_{FC} = contractor direct maintenance cost per failure

H^k_{LC} = total contractor labor hours per failure

C^k_{LC} = average contractor labor rate per failure

C^k_{GC} = average contractor shipping cost per failure

C^k_{EC} = average contractor material cost per failure

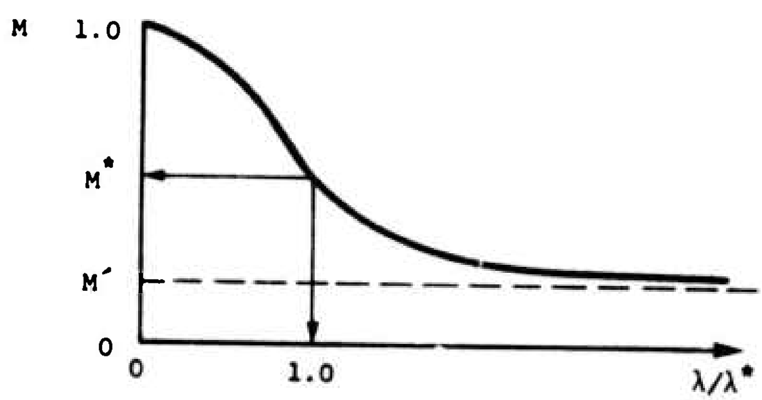
6. RELIABILITY IMPROVEMENT THROUGH MODIFICATION -- M

If a modification to improve reliability is made, we assume that the failure rate is reduced by a factor of M, i.e., $\lambda_{new} = M\lambda$. It is reasonable to assume that the value of M is a function of the actual failure rate and the specified value, say λ^*. Also, it is reasonable to assume that M is limited, say $M > M'$, in that a modification cannot reduce λ to 0. We also require that as λ approaches 0, M approaches 1.

One such function that meets these criteria is[2]

$$M = M' + (1 - M')\left(\frac{M^* - M'}{1 - M'}\right)^{\lambda/\lambda^*} \tag{4}$$

where M^* is the improvement factor to be expected if $\lambda = \lambda^*$. The general shape of this function is shown below:



[2]This function is a form of the Pearl-Reed curve often used in economic growth models.

7. MODIFICATION-TIME DISTRIBUTION

We assume that the time at which a modification can be introduced is a random variable with distribution,

$$f\left(T_m^k\right) = d^k e^{-d^k\left(T_m^k - T_\alpha\right)}, \quad T_m > T_\alpha \tag{5}$$

so that the probability of a modification's being introduced before time T is given by

$$P\left[T_m^k \leq T\right] = 1 - e^{-d^k(T - T_\alpha)} \tag{6}$$

Given that a modification takes place in the interval (T_α, T_β), the expected time of such modification is given by

$$E\left[T_m^k \mid T_\alpha < T_m^k < T_\beta\right] = \left[1 - e^{-d^k\left(T_\beta - T_\alpha\right)}\right]^{-1} \tag{7}$$

$$\cdot \int_{T_\alpha}^{T_\beta} T_m^k d^k e^{-d^k\left(T_m^k - T_\alpha\right)} dT_m^k$$

$$= T_\alpha + \frac{1}{d^k} - \frac{\left(T_\beta - T_\alpha\right) e^{-d^k\left(T_\beta - T_\alpha\right)}}{1 - e^{-d^k\left(T_\beta - T_\alpha\right)}}$$

This equation will be used to amortize user modification costs.

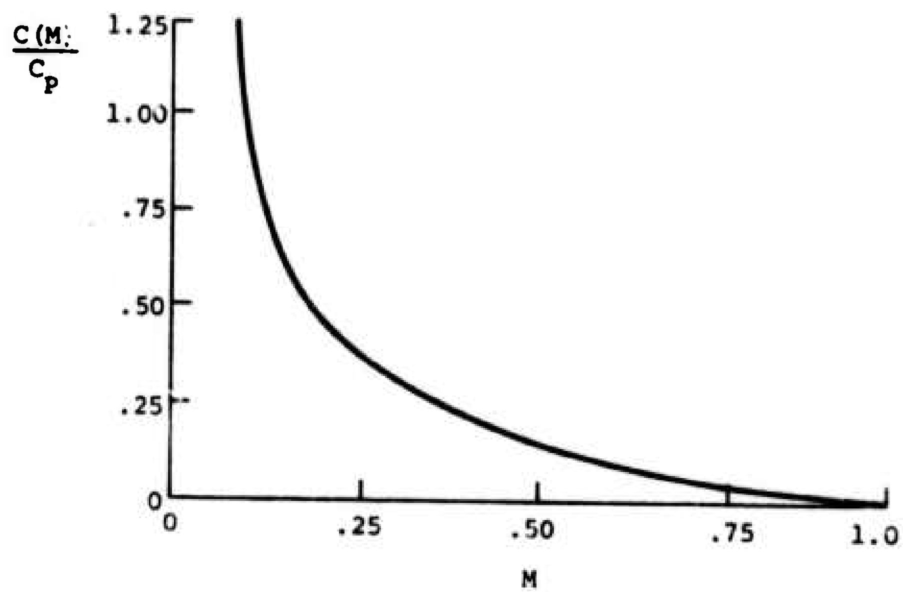
8. COST OF MODIFICATION

The cost of modification is a difficult parameter to predict. It is quite reasonable to assume that the greater the reliability improvement the higher the cost, although many instances must have occurred in which high-cost modifications have yielded minimal reliability improvements.

On the basis of some very limited data, we have developed a modification-cost model that will be used for illustrative purposes and in the interest of completeness.[3] For a failure-rate reduction from λ to $M\lambda$ for an equipment costing C_P, the associated modification cost, including contractor fee, is given by

$$C(M) = 1.06\left[e^{(1 - M)/(10M)} - 1\right]C_P \tag{8}$$

The general shape of this cost function is shown below:



To account for the efficiencies associated with modification when a warranty provision exists, and to subtract contractor fee, we assume that $C^1(M) = AC^0(M)$ where $0 < A \leq 1$ and $C^0(M)$ is as given by Equation 8.

9. PROCUREMENT SIZE -- N^k

The size of the procurement depends on the number of operational units required plus the required number of spares. To calculate the required number of spares, we will assume that a minimum number is established independent of failure rate or pipeline time, such as one spare per squadron.

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[3]Current studies sponsored by Rome Air Development Center and the Institute for Defense Analysis may yield more substantive models.

Using Palm's result that the average number in the pipeline is equal to the expected number of failures per unit time multiplied by the average pipeline time, we obtain the following equation:

$$N^k = N_o + \max\left\{N_o \bar{\lambda}_s H_o T_p^k , N_X\right\} \tag{9}$$

where

N^k = procurement size

N_o = number of operational units

$\bar{\lambda}_s^k$ = average failure rate over the equipment life for spares calculation

T_p^k = average pipeline time

N_x = minimum number of spares

Since most avionic equipment experiences reliability growth, basing the number of spares to be purchased only on the initial failure rate will generally be over-conservative. Therefore, we will estimate $\bar{\lambda}_s$ by considering the initial distribution of λ, i.e., (p_i, λ_i); the possible improvement, M_i, associated with λ_i; and the time at which such improvement may be introduced.

Straightforward consideration of the foregoing possibilities yields

$$\bar{\lambda}_s^k = \frac{1}{T_L} \sum_{i=1}^{n} p_i^k \lambda_i^k \left\{ T_\alpha + \int_{T_\alpha}^{T_L} d^k e^{-d^k\left(T_m - T_\alpha\right)} \left[T_m - T_\alpha - M_i \left(T_L - T_m\right)\right] dT_m \right. \tag{10}$$

$$\left. + \int_{T_L}^{\infty} d^k e^{-d^k\left(T_m - T_\alpha\right)} \left(T_L - T_\alpha\right) dT_m \right\}$$

$$= \frac{1}{T_L} \sum_{i=1}^{n} p_i^k \lambda_i^k \left\{ T_\alpha + M_i \left(T_L - T_\alpha\right) \left[1 - e^{-d^k\left(T_L - T_\alpha\right)}\right] \right.$$

$$\left. + \frac{(1 - M_i)}{d^k} \left[1 - e^{-d^k\left(T_L - T_\alpha\right)} \left\{1 + d^k\left(T_L - T_\alpha\right)\right\}\right] + \left(T_L - T_\alpha\right) e^{-d^k\left(T_L - T_\alpha\right)} \right\}$$

where T_L is the expected equipment lifetime.

10. MODIFICATION STRATEGY

We now consider the strategy the contractor or user is assumed to follow in determining whether a modification to improve reliability is to be attempted during the warranty period.

If at time T_m, the current average failure rate is λ, for N_o operational units an average of $N_o \lambda (T - T_m) H_o$ failures will occur over the period (T_m, T). If C_F is the cost associated with each failure, then $N_o \lambda (T - T_m) H_o C_F$ is the expected remaining failure cost.

If a modification, at time T_m, can reduce the failure rate from λ to $M\lambda$, $(0 < M < 1.0)$, the remaining expected costs will be $N_o (M\lambda)(T - T_m) H_o C_F$, yielding a saving of $N_o (1 - M) \lambda (T - T_m) H_o C_F$.

Therefore, a modification is profitable at time T_m^k if the cost of the modification is less than the saving, or

$$N^k C^k(M) \leq N_o \ (1 - M) \ \lambda^k C_F^k \left(T - T_m^k\right) H_o \qquad (11)$$

where $C^k(M)$ is the modification cost for a λ-improvement factor of M.

We now note that for the no-warranty case, the user will consider the total equipment lifetime (T_L) in determining whether a modification is profitable. Under a warranty provision, the contractor will be primarily concerned only with the warranty period.[4] Upon replacing T in Equation 11

[4]For the warranty case, if an option for warranty renewal does not exist, the user may request a modification and be willing to pay for it. If such an option does exist, the contractor must consider the possibility of warranty-period extension. Such alternatives are not considered in the model.

by T_x^k, we have the λ-dependent strategy:

$$T_\alpha < T_m^k < T_i^k$$

where

$$T_i^k = \max \left\{ T_\alpha \ , \ T_X^k - \frac{N^k C^k (M_i)}{N_o (1 - M_i) \lambda_i^k \, C_F^k \, H_o} \right\} \tag{12}$$

$$C_F^k = \begin{cases} C_{FU}^0 & , \ k = 0 \\ C_{FC}^1 & , \ k = 1 \end{cases} \tag{13}$$

$$T_X^k = \begin{cases} T_L & , \ k = 0 \\ T_w & , \ k = 1 \end{cases} \tag{14}$$

11. EXPECTED MODIFICATION COSTS, C_{MOD}

Without discounting or amortization, the expected modification costs are given by

$$C_{MOD} = N \sum_{i=1}^{n} p_i \left[1 - e^{-d\left(T_i - T_\alpha\right)} \right] C(M_i) \ , \ T_\alpha < T_i < T_w \tag{15}$$

For a modification interval (T_α, T_i) associated with λ_i, the expected time of modification is, from Equation 7,

$$\bar{T}_i = T_\alpha + \frac{1}{d} - \frac{\left(T_i - T_\alpha\right) e^{-d\left(T_i - T_\alpha\right)}}{1 - e^{-d\left(T_i - T_\alpha\right)}} \tag{16}$$

We now consider the no-warranty and warranty cases separately.

11.1 No-Warranty Case -- C^0_{MOD}

For the no-warranty case, the user will expect to incur modification costs at $\bar{T}^0_i$ if $\lambda = \lambda_i$. This cost pertains to the period $(\bar{T}_i, T_w)$ and is to be amortized on a straight-line basis over $(\bar{T}_i, T_L)$ since it is assumed to represent a major capital investment. Hence,

$$C^0_{MOD} = N^c \sum_{i=1}^{n} P^0_i \left[1 - e^{-d^0\left(T^0_i - T_\alpha\right)}\right] C^0(M_i) \left(\frac{T_w - \bar{T}_i}{T_L - \bar{T}_i}\right) \qquad (17)$$

11.2 Warranty Case -- C^1_{MOD}

For the warranty case, the contractor will expect to incur modification costs at $\bar{T}^1_i$ if $\lambda = \lambda_i$. Our basic premise is that all estimated contractor warranty costs are included in the contract. However, since the modification costs are incurred at time $\bar{T}^1_i$ but are paid for at time 0, to be competitive the contractor would normally discount them. These discounted costs are then amortized in the same fashion as for the no-warranty case.[5]

Hence,

$$C^1_{MOD} = N^1 \sum_{i=1}^{n} P^1_i \left[1 - e^{-d^1\left(T^1_i - T_\alpha\right)}\right] \frac{C^1(M_i)}{\left(1 + I/12\right)^{T_w}} \left(\frac{T_w - \bar{T}_i}{T_L - T_i}\right) \qquad (18)$$

where I is the yearly interest rate.

12. TOTAL DIRECT MAINTENANCE COST -- C_{DM}

Total direct maintenance cost is defined to be equal to the sum of all direct costs associated with repairing failed equipment. Since we assume that cost per failure is constant, we employ the average failure rate given

[5] Note that for warranty-repair costs the user may make periodic payments rather than pay at equipment delivery. Because of this possibility, we have not discounted these costs, although it may be reasonable to do so if periodic payments are not made.

by Equation 22 to yield the following:

- User total direct maintenance cost --

$$C^k_{DMU} = N_o \overline{\lambda}^k C^k_{FU} H_o T_w \tag{19}$$

- Contractor total direct maintenance cost --

$$C^k_{DMC} = N_o \overline{\lambda}^k C^k_{FC} H_o T_w \tag{20}$$

To solve for $\overline{\lambda}$, we consider the initial distribution of λ, (p_i, λ_i); the possible improvement, M_i, associated with λ_i; and the probability that such improvement will be initiated during the warranty period.

Straightforward enumeration of events yields

$$\overline{\lambda} = \frac{1}{T_w} \sum_{i=1}^{n} p_i \lambda_i \left\{ T_\alpha + \int_{T_\alpha}^{T_i} de^{-d\left(T_m - T_\alpha\right)} \left[T_m - T_\alpha + M_i \left(T_w - T_m \right) \right] dT_m \right. \tag{21}$$

$$\left. + \int_{T_i}^{\infty} de^{-d\left(T_m - T_\alpha\right)} \left(T_w - T_\alpha \right) dT_m \right\}$$

The first term gives the average rate over $(0, T_\alpha)$ when no modification is possible. The second term represents the following:

- Probability that $\lambda = \lambda_i$
- Probability that a modification can be achieved within time $(T_m, T_m + dT_m)$
- Failure rate λ_i over (T_α, T_m)
- Failure rate $M_i \lambda_i$ over $(T_w - T_m)$

The third term represents the probability that no modification is possible over (T_α, T_i); therefore, the failure rate does not change from the initial value.

Upon adding the "k" superscript and performing the integration, we obtain the following equation for $\bar{\lambda}^k$:

$$\bar{\lambda}^k = \frac{1}{T_w} \sum_{i=1}^{n} P_i^k \lambda_i^k \left\{ T_\alpha + \left[M_i^k \left(T_w - T_\alpha \right) \right] \left[1 - e^{-d^k \left(T_i^k - T_\alpha \right)} \right] \right. \tag{22}$$

$$+ \frac{\left(1 - M_i^k\right)}{d^k} \left[1 - e^{-d^k \left(T_i^k - T_\alpha \right)} \left\{ 1 + d^k \left(T_i^k - T_\alpha \right) \right\} \right]$$

$$\left. + \left(T_w - T_\alpha \right) e^{-d^k \left(T_i^k - T_\alpha \right)} \right\}$$

13. RISK FACTOR

The longer the warranty period, the more risk and uncertainty a contractor faces in establishing a warranty-cost estimate. In order to protect himself, the contractor may consider a risk factor to apply to his estimated cost, which increases with T_w. To account for this possibility, we introduce such a factor, which will be defined as

$$R(T_w) = \left(1 + r\right)^{T_w/12} \tag{23}$$

where

$R(T_w)$ = total risk factor associated with a warranty period of T_w months

$1 + r$ = risk factor for first year

Thus, if $r = 0.03$, then $R(12) = 1.03$, $R(24) = 1.061$, $R(36) = 1.093$, etc.

14. LIFE-CYCLE COSTS

We now apply the generic life-cycle warranty cost model, extended to reflect the concepts used in developing the submodels discussed above.

14.1 <u>No Warranty</u>

Without a warranty the user incurs all costs of failure. From the generic model, extended to reflect amortization and modification,

$$LCC^0_{T_w} = N^0 C^0_P A_{T_w} + C^0_{MOD} + C^0_{DMU} + C^0_{ISU} A_{T_w} + C^0_{RSU} \cdot T_w \tag{24}$$

where

C^k_{ISU} = initial user maintenance-support costs

C^k_{RSU} = recurring user-maintenance support costs per month

A_{T_w} = amortization factor = T_w/T_L

14.2 Warranty

With a warranty, the same form applies except that we apply the risk and fee factors to all costs the contractor expects to incur because of the warranty provision. We also assume that contractor indirect support costs are reflected in the labor rate. Therefore,

$$LCC^1_{T_w} = N^1 C^1_P A_{T_w} + \left[C^1_{MOD} + C_{DMC}\right] R(T_w)\ (1 + P) \tag{25}$$

$$+ C^1_{DMU} + C^1_{ISU} A_{T_w} + C^1_{RSU} \cdot T_w$$

Except for $\left(C^1_{DMU} + C^1_{ISU} \cdot A_{T_w} + C^1_{RSU} \cdot T_w\right)$, $LCC^1_{T_w}$ represents the total amortized contractor costs for the purchase, warranty-repair, and modification of the N^1 units. Over the total lifetime, we can calculate the unit price as

$$C^1_P = C^0_P + \frac{\left(C^1_{MOD^*} + C^1_{DMC}\right) R(T_w)\ (1 + P)}{N^1} \tag{26}$$

where $C^1_{MOD^*}$, the unamortized-discounted modification costs, is given by

$$C_{MOD^*} = \sum_{i=1}^{n} p^1_i \left[1 - e^{-d^1\left(T^1_i - T_\alpha\right)}\right] \frac{C^1(M_i)}{\left(1 + I/12\right)^{T_i}} \tag{27}$$

15. WARRANTY PRICE ANALYSIS

We now consider the break-even or "indifference" price to pay for units with a warranty provision over a period of T_w months. An indifference price is a price whereby the expected total user cost under warranty is not greater than the total cost the user would expect to incur without a warranty.

We develop the indifference unit price, say C_P^*, by letting

$$C_P^* = C_P^0 + C_{INC}^* \tag{28}$$

where C_{INC}^* is the price increment due to warranty, consisting of the amortized modification costs $\left(C_{MOD}^1\right)$ and the unamortized contractor direct maintenance costs $\left(C_{DMC}^1\right)$.

For a given value of C_P^*, the total amortized life-cycle costs to the user will be

$$LCC_{T_w}^* = N^1 \left[C_P^0 A_{T_w} + C_{INC}^* A_{T_w}^*\right] + C_{DMU}^1 + C_{ISU}^1 A_{T_w} + C_{RSU}^1 \cdot T_w \tag{29}$$

where $A_{T_w}^*$ is the amortization factor to apply to C_{INC}^*. For C_P^* to yield an amortized life-cycle cost equal to the no-warranty case (i.e., $LCC_{T_w}^0$), we must have

$$N^1 C_{INC}^* A_{T_w}^* = LCC_{T_w}^0 - N^1 C_P^0 A_{T_w} - C_{DMU}^1 - C_{ISU} A_{T_w} - C_{RSU} \cdot T_w \tag{30}$$

Therefore, the value of C_{INC}^* is equal to

$$C_{INC}^* = \frac{LCC_{T_w}^0 - N_1 C_P^0 A_{T_w} - C_{DMU}^1 - C_{ISU}^1 A_{T_w} - C_{RSU} \cdot T_w}{N_1 A_{T_w}^*} \tag{31}$$

To obtain the value of $A_{T_w}^*$, we use proportionate weighting of the average modification-cost amortization factor, say $\overline{A}_M$, and that of the

contractor direct maintenance cost (A.F. = 1.0), yielding

$$A^*_{T_w} = \frac{C^1_{MOD} \cdot \bar{A}_M + C^1_{DMC}}{C^1_{MOD} + C^1_{DMC}} \tag{32}$$

where

$\bar{A}_M$ = average modification-cost amortization factor

$$= \sum_{i=1}^{n} p_i \left[1 - e^{-d^1 (T_i - T_\alpha)}\right] \left(\frac{T_w - \bar{T}_i}{T_L - \bar{T}_i}\right) \tag{33}$$

The indifference unit-price percentage increment per year is then

$$I_{T_w} = 1200 \left(\frac{C^*_P - C^0_P}{C^0_P \cdot T_w}\right) \tag{34}$$

$$= 1200 \left(\frac{C^*_{INC}}{C^0_P \cdot T_w}\right)$$

We note that with a price of C^*_p, if the contractor can provide a reliability better than anticipated in the model (either initially or through modification), or if he can reduce repair or modification time and/or costs without adversely affecting the failure rate, he can achieve a higher profit at no additional cost to the user. The user, of course, will also benefit from better reliability or shorter repair periods and, with the indifference price of C^*_p, is assured that he is not incurring costs over the warranty period greater than the costs he would incur without the warranty.

16. SUMMARY OF DATA-INPUT REQUIREMENTS

The data-input requirements of the model are summarized as follows:

- <u>General</u>

  C^0_P = unit purchase price without warranty

  N_o = number of operational units

  H_o = operating hours per month per unit

T_L = equipment lifetime (months)

T_w = warranty period (months)

I = yearly interest rate for discounting

- <u>Reliability</u>

$\left(p_i^k, \lambda_i^k\right)$ = prior distribution of failure rate

λ^* = specified failure rate

- <u>Direct Maintenance Cost</u>

H_{LU}^k = total user labor hours per failure

C_{LU}^k = average user labor rate per failure

C_{GU}^k = average user shipping costs per failure

C_{EU}^k = average user material costs per failure

H_{LC}^k = total contractor labor hours per failure

C_{LC}^k = average contractor labor rate per failure

C_{GC}^k = average contractor shipping costs per failure

C_{EC}^k = average contractor material costs per failure

- <u>Modification Statistics</u>

T_α = minimum number of months before modification is possible

M^* = failure-rate improvement if $\lambda = \lambda^*$

M' = minimum value of failure-rate improvement factor

d^k = rate at which modification can be introduced

A = factor to adjust estimated warranty modification costs to the no-warranty case

- <u>Procurement Size</u>

N_x = minimum number of spares

T_p^k = pipeline time (months)

- Risk and Profit

  r = factor such that (1 + r) equals risk burden for first year

  P = contractor fee

- Support Costs

  C^k_{ISU} = user initial support costs

  C^k_{RSU} = user recurring support costs

17. ILLUSTRATIVE MODEL APPLICATIONS

In this section, the model is applied to four sample procurements that are believed to represent a good cross-section of equipment type, complexity, reliability, and cost.

These sample procurements are not actual cases; they were developed from data obtained during the study from various sources and are believed to be representative. It is cautioned, however, that the conclusions drawn from the examples apply only to the set of data values used, and general inferences about the value of warranty should not be made on the basis of these examples.

The four procurements are summarized briefly below.

17.1 Procurement A: Accelerometer (F105)

Procurement A represents a large purchase of a relatively inexpensive, high-MTBF unit. We have assumed that this item is already in the inventory, so that many types of initial support costs will not be incurred. The life-cycle cost analysis applies only to the new-procurement items.

Many of the data elements used in the model were obtained from an RADC-sponsored study performed by Hughes Aircraft Company.[6] Two major changes in the data were made.

In the Hughes report, it was assumed that the MTBF with a warranty would be twice that of the MTBF without warranty. It is believed that this assumption is extreme. Instead, we have assumed that the prior distribution of the MTBF is somewhat better for the warranty case, yielding specifically an average MTBF for the warranty case that is approximately five percent better than the no-warranty case; but we also assume that the modification-introduction rate is greater when a warranty exists.

The other change concerns warranty administration costs. In the Hughes study, a monthly warranty-administration cost of $4,000 per month was assumed. The unit has an approximate MTBF of 5,000 hours, and 1,000 units operating 75 hours per month would generate approximately 15 failures per year. Yearly costs of almost $50,000 seems too high to administer 15 warranty claims. We have therefore reduced the warranty administration costs to $800 per month.

17.2 Procurement B: Gyro (F111)

Procurement B represents a small purchase of a moderately priced, moderate-MTBF unit that is already in the Air Force inventory. An attempt was made to use as many data on the existing Air Force A24G-26 gyro warranty procurement as possible, but not all required data were available (e.g., the current MTBF of the gyro under warranty was not obtainable at the time of this study).

[6] RADC Report TR 39-363, *Airborne Electronic Equipment Lifetime Guarantee*, November 1969.

17.3 Procurement C: Magnetic Drum (F105)

Procurement C represents a large purchase of a moderately expensive, moderate-MTBF unit that is already in the Air Force inventory. The Hughes study referenced above was used to obtain many of the data elements.

17.4 Procurement D: Inertial Navigation System (A6E)

Procurement D represents a moderate-size purchase of a very complex, expensive, low-MTBF system that is not in the Air Force inventory. Many of the data were obtained from a recent ARINC Research life-cycle-cost study of alternative navigation systems for the A-6E aircraft.[7]

17.5 Data Inputs

Table III-1 lists the data inputs used in exercising the model for the four procurements. For each procurement the following constant parameters were used:

Equipment lifetime (T_L), 10 years

Minimum period before modification (T_A), 3 months

Yearly interest rate (I), 10 percent

Risk factor (r), 3 percent

Contractor fee (P), 10 percent

We also assumed that without a warranty, the probability of a modification in three years is equal to 0.75. Therefore,

$$1 - e^{-d^0(36-3)} = 0.75$$

or

$$d^0 = 0.042$$

With warranty, we assumed a 0.90 probability over the same time period, yielding a rate of $d^1 = 0.070$.

Other general aspects of these data are as follows:

- MTBFs rather than failure rates are listed because of convention. Conversion to failure rate ($\lambda = 1/\theta$) is required for model application.
- For each case two possible MTBF values are used. These values encompass the best estimate of actual MTBF available at the time of model exercise. Generally, the initial MTBF distribution with warranty is equal to or slightly better than that for no-warranty.

---

[7] *Life-Cycle Cost Analysis of Alternative Navigation Systems for the A-6E Aircraft (Preliminary)* -- ARINC Research Corporation, April 1973.

TABLE III-1

DATA INPUTS FOR MODEL APPLICATION

Factor	Symbol	Procurement A Accelerometer		Procurement B Gyro		Procurement C Magnetic Drum		Procurement D Inertial Navigation	
		No W*	W*	No W	W	No W	W	No W	W
Unit purchase price (dollars)	C^o_P	720	--	6,040	--	18,000	--	60,000	--
Number of operational units	N_o	1,000	1,000	100	100	1,000	1,000	350	350
Operating hours per month	H_o	75	75	50	50	75	75	70	70
Equipment lifetime (months)	T_L	120	120	120	120	120	120	120	120
MTBF distribution	$(p_1;\theta_1)$	0.5;4000	0.4;4000	0.5;900	0.5;900	0.5;265	0.4;265	0.5;200	0.4;200
	$(p_2;\theta_2)$	0.5;6000	0.6;6000	0.5;1350	0.5;1350	0.5;500	0.6;500	0.5;300	0.6;300
Specified MTBF	θ^*	7,600	7,600	2,240	2,240	530	530	650	650
User labor hours per failure	H_{LU}	8	1	60	2	50	4	130	10
User labor rate per failure	C_{LU}	12	12	15	12	13	12	15	12
User shipping cost per failure	C_{GU}	20	10	20	10	20	10	20	20
User material cost per failure	C_{EU}	50	0	250	0	200	0	600	0
Contractor labor hours per failure	H_{LC}	--	5	--	40	--	30	--	100
Contractor labor rate per failure	C_{LC}	--	16	--	16	--	16	--	18
Contractor shipping cost per failure	C_{GC}	--	10	--	10	--	20	--	20
Contractor material cost per failure	C_{EC}	--	30	--	175	--	125	--	400
Minimum modification time (months)	T_s	3	3	3	3	3	3	3	3
Failure rate improvement if $\lambda = \lambda^*$	M^*	0.75	0.75	0.90	0.90	0.75	0.75	0.50	0.50
Minimum value of F.E. improvement factor	M'	0.40	0.40	0.25	0.25	0.40	0.40	0.[illegible]0	0.20
Rate for modification introduction	d	0.042	0.070	0.042	0.070	0.042	0.070	0.042	0.070
Factor to adjust modification costs for warranty case	A	--	0.80	--	0.80	--	0.80	--	0.80
Minimum number of spares	N_X	40	40	20	20	40	40	35	35
Pipeline time (months)	T_P	0.75	0.75	2.0	2.0	1.95	1.15	2.8	2.8
Risk factor	r	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Contractor fee	P	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
User initial support costs	C_{ISU}	20,000	0	20,000	0	50,000	10,000	20×10^6	2×10^6
User recurring support costs	C_{RSU}	500	800	500	800	500	8,000	20,000	15,000

*No W = No Warranty; W = Warranty.

- User labor hours per failure without warranty are generally greater than contractor labor hours per failure with warranty. This recognizes the fact that engineering and technical expertise of contractor personnel is generally higher than that of military personnel. For this reason, the contractor labor rate is generally higher than the military labor rate.

- Since contractors are likely to be more cost conscious, contractor material cost per failure is generally lower than corresponding user costs. However, the contractor costs are then burdened with fee.

- For cases where it is assumed that the item is already in the inventory, user initial support costs are minimal and are much lower for the warranty case than for the no-warranty case.

17.6 Model Exercise and Results

To exercise the model, a conversational (timesharing) program in the FORTRAN language was developed.[8] The basic parameter of interest was the total amortized savings (loss) of a warranty for a period of T_w months, i.e.,

$$WS_{T_w} = LCC^{0}_{T_w} - LCC^{1}_{T_w}$$

The data (except the MTBF distribution and the warranty period) can be either stored in the program through DATA statements or entered through the terminal. The MTBF distribution is inputted through the terminal followed by the initial warranty period to be considered, the increment in the warranty period, the number of periods to be considered, and a print code.

For code 0, the output consists of the following:

- User costs per failure (k = 0,1)
- Procurement size (k = 0,1)
- Failure-rate improvement factors for each MTBF and associated costs (k = 0,1)
- Warranty savings for each period to be considered

If the print code 1 is entered, detailed information is provided for each warranty period.

Exhibit III-1 presents sample outputs for the magnetic drum procurement.

---

[8]The program was written in FORTRAN specifically for the CDC-KRONOS Timesharing System using the CDC-6400 computer. With minor changes, the program should be appropriate for most other timesharing systems with FORTRAN capability. Conversion to batch-processing is also possible.

```
*****    MAGNETIC DRUM    *****

RNH,MA=77777

INPUT # OF MTBFS,NO WRNTY. FIRST
? 2,2
INPUT MTBFS & PROBS.-NO WARNTY. FIRST
? 265,.5,500,.5
? 265,.4,500,.6

USER COST/FAILURE    379     58

CNTR.COST/FAILURE      0    625

PROCUREMENT SIZE:NO-W. AND W.    1398   1167

W.R.IMPROVEMENT FACTOR & MOD. COST
  1 .6042    2372 .6042    1393

  2 .7339    1766 .7339    1413

INPUT MIN-TW,INC,# PERIODS,PRINT CODE
? 12,12,10,0

W.PERIOD   T.SAVINGS
    12      497079
    24      729420
    36      342362
    48     1304172
    60     1500354
    72     1583135
    84     1351932
    96     1340603
   108     1644340
   120     1302691
    ****************

INPUT DATA-CHANGE CODE (0=NONE)
? 0
INPUT MIN-TW,INC,# PERIODS,PRINT CODE
? 72,6,5,1
```

EXHIBIT III-1
SAMPLE COMPUTER OUTPUT: MAGNETIC DRUM

```
 #### WARRANTY PERIOD =  72 MOS. ####

MOD.TIME INTERVAL,(MOS)
     NO-W. WRNTY.
  1  69.0  37.4
  2  49.2   1.6

                          NO WARRANTY  WARRANTY

AVG. MTBF-(O,IE)           446.62     447.63

DIRECT M COST-USER    10517277     699609

DIRECT M COST-CNTR.          0   7533837

EXPCTD. MOD.COST  TOTAL  AMORTIZED
USER (K=0)        2474653  1268245
CNTR.(K=1)         332325   453766

                     TOTAL   MONTHLY  TOT.SUP. MO.SUP.  UNIT
                   COST(A) COST(A)   COST(A) COST(A) PRICE

NO WARRANTY    25977922   360304 10583277  146990  18000

WRNTY  72MOS. 24389787   338747  1281609   17800  27422

WRNTY.PRICE INCREMENT/YR.(PCT.)= 3.72

TOTAL COSTS W/O AMORT.--NO.WIW  36621235  32796187

WARRANTY SAVINGS (TOT.AMORT.COST)  $  1598135

INDIFFERENCE W.PRICE=$ 29202 (10.38 PCT.)


 #### WARRANTY PERIOD =  73 MOS. ####

MOD.TIME INTERVAL,(MOS)
     NO-W. WRNTY.
  1  75.0  43.4
  2  49.2   7.6
```

EXHIBIT III-1 (continued)

```
                     NO WARRANTY   WARRANTY

AVG. MTBF-(O,TW)          451.20     469.10

DIRECT M COST-USER    11280023     723299

DIRECT M COST-CNTR.          0    7794166

EXPCTD. MOD.COST   TOTAL   AMORTIZED
USER (K=0)         2493709   1425427
CNTR.(K=1)         1132277    690746

                   TOTAL   MONTHLY   TOT.SUP. AV.SUP.  UNIT
                  COST(A) COST(A)    COST(A) COST(A)  PRICE

NO WARRANTY    28030550    360007 11351523  145532   13000

WRNTY  78MOS. 26318204    337413  1353799   17356   28196

WRNTY.PRICE INCREMENT/YR.(PCT.)= 8.71

TOTAL COSTS W/O AMORT.--NO.W:W   37406732  33673804

WARRANTY SAVINGS (TOT.AMORT.COST)  $  1762346

INDIFFERENCE W.PRICE=$ 30150 (10.38 PCT.)


 #### WARRANTY PERIOD =  84 MOS.  ####

MOD.TIME INTERVAL,(MOS)
     NO-W.  WRNTY.
  1  81.0   49.4
  2  49.2   13.6

                     NO WARRANTY   WARRANTY

AVG. MTBF-(O,TW)          455.25     434.00

DIRECT M COST-USER    12039595     754963

DIRECT M COST-CNTR.          0    8135330
```

EXHIBIT III-1 (continued)

EXPCTD. MOD.COST	TOTAL	AMORTIZED
USER (K=0)	2508517	1584022
CNTR.(K=1)	1319146	876092

	TOTAL COST(A)	MONTHLY COST(A)	TOT.SUP. COST(A)	MO.SUP. COST(A)	UNIT PRICE
NO WARRANTY	30181416	359303	12116595	144245	18000
WRNTY 84MOS.	28329435	337255	1433963	17071	28960

WRNTY.PRICE INCREMENT/YR.(PCT.)= 8.70

TOTAL COSTS W/O AMORT.--NO.W&W 38184112 34634235

WARRANTY SAVINGS (TOT.AMORT.COST) $ 1851982

INDIFFERENCE W.PRICE=$ 30930 (10.26 PCT.)

WARRANTY PERIOD = 90 MOS.

MOD.TIME INTERVAL,(MOS)

	NO-W.	WRNTY.
1	85.2	55.4
2	49.2	19.6

	NO WARRANTY	WARRANTY
AVG. MTBF-(0,TW)	458.90	494.40
DIRECT M COST-USER	12796793	791868
DIRECT M COST-CNTR.	0	8533057

EXPCTD. MOD.COST	TOTAL	AMORTIZED
USER (K=0)	2516814	1742127
CNTR.(K=1)	1435600	1030818

	TOTAL COST(A)	MONTHLY COST(A)	TOT.SUP. COST(A)	MO.SUP. COST(A)	UNIT PRICE

EXHIBIT III-1 (continued)

```
NO WARRANTY     32279420    358660 12879293  143103  18000

WRNTY  90MOS. 30405108    337835  1519368   16882  29728

WRNTY.PRICE INCREMENT/YR.(PCT.)= 8.69

TOTAL COSTS W/O AMORT.--NO.W&W  38952607  35659108

WARRANTY SAVINGS (TOT.AMORT.COST)  $  1874312

INDIFFERENCE W.PRICE=$ 31636 (10.10 PCT.)


 #### WARRANTY PERIOD =  96 MOS. ####

MOD.TIME INTERVAL,(MOS)
     NO-W. WRNTY.
  1  85.2  61.4
  2  49.2  25.6

                     NO WARRANTY  WARRANTY

AVG. MTBF-(O,TW)         462.17     501.79

DIRECT M COST-USER    13553464     832215

DIRECT M COST-CNTR.          0    9967832

EXPCTD. MOD.COST   TOTAL   AMORTIZED
USER (K=0)        2516814  1897064
CNTR.(K=1)        1508041  1165391

                   TOTAL   MONTHLY  TOT.SUP. MO.SUP.  UNIT
                  COST(A) COST(A)   COST(A) COST(A) PRICE

NO WARRANTY     34373728    358060 13641464  142099  18000

WRNTY  96MOS. 32533125    338887  1608215   16752  30509
```

EXHIBIT III-1 (continued)

```
WRNTY.PRICE INCREMENT/YR.(PCT.)= 9.69

TOTAL COSTS W/O AMORT.--NO.W&W  39712278  36736325

WARRANTY SAVINGS (TOT.AMORT.COST)  S  1840603

INDIFFERENCE W.PRICE=S 32311 ( 9.94 PCT.)

    ################

INPUT DATA-CHANGE CODE (0=NONE)
? -1
    STOP

SS        4.160 SECS.

RUN COMPLETE.
```

EXHIBIT III-1 (concluded)

Figures III-1 through III-4 display the warranty savings as a function of the warranty period. They show that the "optimum" warranty period increases as equipment complexity and total cost increase. Table III-2 summarizes pertinent data obtained from the computer runs.

For the accelerometer procurement, it is seen that the maximum warranty savings are obtained for a one-year period. However, the savings of $830 are less than one percent of the amortized life-cycle cost for the no-warranty case with approximately equal MTBFs. For the input data used, the decision to employ a warranty for this procurement would best be based on factors other than those considered directly in the model.

For the gyro procurement, the maximum warranty savings occur when $T_W = 2$ years, yielding a saving of about 4.4 percent. The MTBF over the first two years is slightly better for the no-warranty case (1,150 vs. 1,080) because of the assumption that the user's strategy for reliability improvement through modification is based on the total lifetime (10 years in this case) while the contractor considers only the warranty period.

The amortized modification cost to the user was $4,050 under the no-warranty procurement. This result provides an example of a case in which the user might consider it worthwhile to pay for a modification while the unit is under warranty.

A warranty period of 7.5 years provides the maximum savings for the magnetic-drum procurement. Over this period, a total saving of approximately $1,874,000 in amortized costs will be realized, which is about 5.8 percent of the amortized life-cycle cost without warranty. Over the 7.5-year warranty period, the average MTBF for the no-warranty case is 459 hours, versus 494 hours for the warranty procurement.

For this procurement, the pipeline times for contractor repair were less than that for the Air Force depot repair (1.15 months vs 1.95 months). This, in conjunction with the slightly better prior MTBF distribution for the warranty case, caused the significant procurement-size difference, which accounts for most of the savings.

If equal pipeline times of 1.5 months are assumed, then the procurement sizes for no-warranty and warranty are 1,237 and 1,218, respectively. The maximum warranty saving occurs at 4-1/2 years and is equal to $361,500. The average MTBF is almost equal for both cases over this period.

The inertial-navigation system procurement is one for which the best warranty period is the total lifetime of ten years. Over this period, a saving of more than $18 million is realized, which is approximately 24 percent of the 10-year life-cycle cost. The average MTBF with warranty is 619 hours, versus 540 without warranty.

The major part of the savings is in the initial support costs ($20 million without warranty versus $2 million with warranty). Since this procurement represents a new inventory item that is complex, such savings in test and support equipment, training, manuals, and other start-up costs are quite possible.

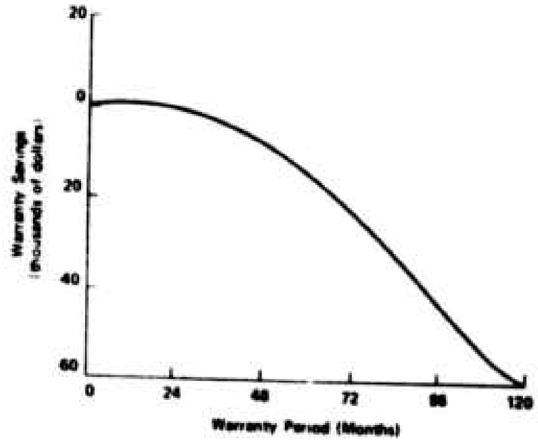

FIGURE III-1

WARRANTY SAVINGS VS WARRANTY PERIOD, ACCELEROMETER PROCUREMENT

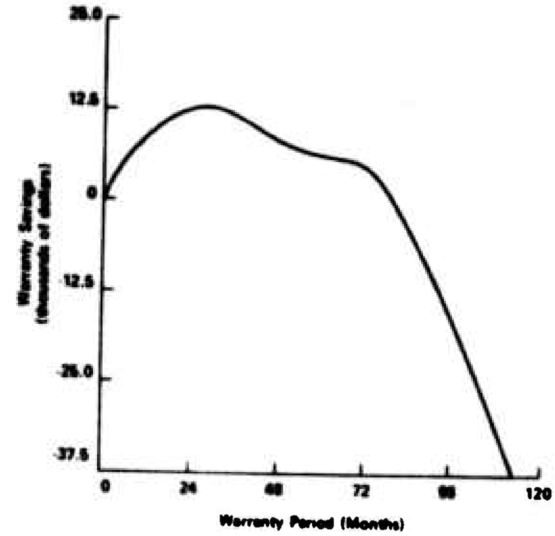

FIGURE III-2

WARRANTY SAVINGS VS WARRANTY PERIOD, GYRO PROCUREMENT

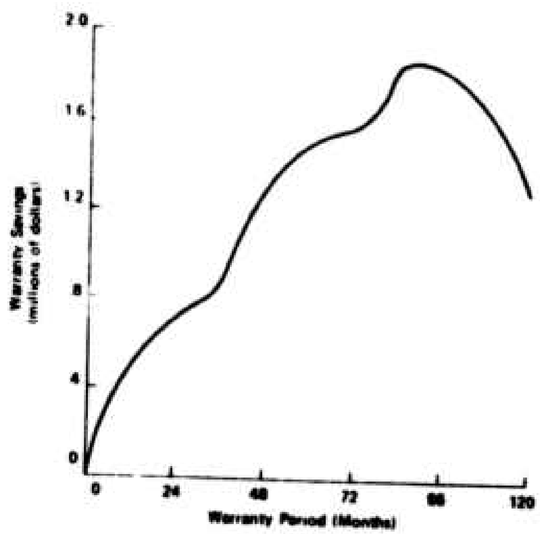

FIGURE III-3

WARRANTY SAVINGS VS WARRANTY PERIOD, MAGNETIC DRUM PROCUREMENT

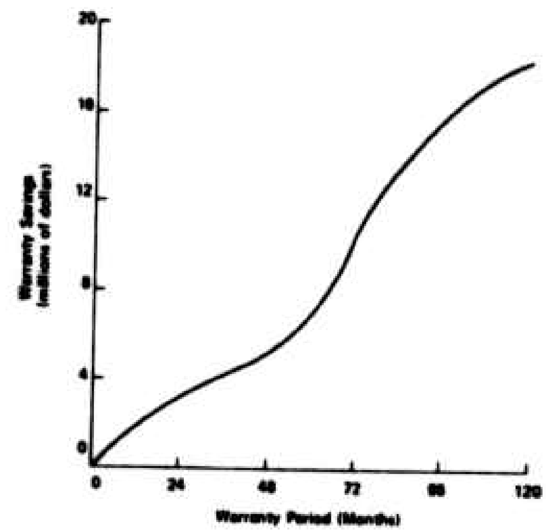

FIGURE III-4

WARRANTY SAVINGS VS WARRANTY PERIOD; INERTIAL NAVIGATION PROCUREMENT

TABLE III-2

LIFE-CYCLE COST DATA FOR THE OPTIMUM WARRANTY PERIOD

Factor		Accelerometer	Gyro	Magnetic Drum	INS
Optimum Warranty Period		1 year	2 years	7.5 years	10 years
Total Amortized Cost (Dollars)	No Warranty	113,750	287,450	32,280,000	75,145,000
	Warranty	112,920	274,900	30,405,000	56,894,000
Warranty Savings	Dollars	830	12,550	1,874,000	18,251,000
	Percent of LCC^{O}	0.73	4.37	5.81	24.28
Unit Price (Dollars)	No Warranty	720	6,040	18,000	60,000
	Warranty (% C_p^O/yr.)	744 (3.3%)	6,931 (7.4%)	29,730 (8.7%)	116,100 (9.35%)
	Indifference (% C_p^O/yr.)	744 (3.3%)	7,036 (8.2%)	31,626 (10.1%)	157,050 (16.2%)
Average MTBF over T_w (hours)	No Warranty	4,945	1,147	486	540
	Warranty	5,000	1,080	494	669
Procurement Size (Number of Units)	No Warranty	1,040	120	1,308	471
	Warranty	1,040	120	1,167	451

In addition, the average user cost of failure is about $200 greater without the warranty than the user-plus-unburdened-contractor cost per failure with warranty. Over the ten-year period, approximately 4,900 failures will occur. At a $200 saving per failure, warranty savings in repair costs total nearly $1,000,000; after reduction for the fee and risk burden, this is still significant.

18. DISCUSSION OF THE MODEL

The life-cycle model presented in this appendix is believed to include the major factors that should be considered quantitatively in evaluating the cost implications of failure-free warranty provision. The model is perhaps somewhat more complex than "typical" life-cycle cost models in that it specifically treats the possibility of reliability growth through engineering modification, the cost of such modification, and the resultant savings in maintenance cost. Recognition is also given to the fact that the knowledge of equipment MTBF is often vague when life-cycle cost models are applied. The use of a prior distribution of MTBF is believed to be a reasonable approach.

It is noted that if the modification introduction rate, d, is set equal to zero and the MTBF prior distribution is concentrated at a single point, the model reduces to the model-form typically proposed for warranty-cost evaluation.

Although the equations for the submodels are not particularly difficult to solve, it is recommended that a computer program be employed for performing variational analysis, particularly with respect to determining whether a warranty is beneficial and, if it is, the warranty period that should be used to maximize life-cycle cost savings.

The submodels used to determine the time for introducing reliability modification, cost of such modification, and amount of improvement must be considered more illustrative than factual. Research on past avionics programs should provide more definitive predictive equations for these factors.

Three possible limitations of the model deserve some discussion. For reliability-improvement modification, we have assumed that during the warranty period only one such modification, at most, is performed. This assumption applies for both the warranty and no-warranty cases and, therefore, should not introduce any serious bias in comparing the two cases. We can also argue that the single modification time and the associated reliability improvement and cost can be considered to be averages over possibly several instances of modification. The concentration into one modification yields a significant reduction in model complexity.

The second limitation concerns the restriction of the life-cycle cost analysis only to the warranty period (except for the amortization of capital expenditures). If a warranty provision were not to have an option for renewal or at least an option for a follow-on contractor maintenance program, then a complete life-cycle cost analysis would be a fairly straightforward extension, although not without some complications in treating the necessary build-up of a user's maintenance capability.

For programs requiring a large investment in training and support-equipment materials when a warranty expires, a prudent policy would be to include such option in the initial agreement. On the other hand, it also is reasonable (from both the contractor and user viewpoints) to leave the terms of a possible renewed agreement open for negotiation on the basis of the history of the initial period of warranty. Considering such an option and negotiated price in an overall model would be a difficult task, although further research in this area is encouraged.

The third limitation concerns the fact that we have not included unverified failures in the model. Mean time between unscheduled removals (MTBUR), which consists of verified plus unverified failures, can be significantly higher than MTBF. Since unscheduled removals can have a major impact on life-cycle cost, the model should be extended to include unverified failures.

We do believe, however, that despite these limitations the proposed model can still serve well, especially for the case in which a decision to include a warranty has been made and the most cost-effective warranty period has yet to be determined. We also note that any model of a complex process cannot possibly include all factors bearing on the decision, and the life-cycle cost model we propose is certainly no exception. However, it will provide quantitative estimates of cost and reliability associated with a warranty decision, which certainly represent two of the most important decision factors.

APPENDIX IV

SUMMARY OF AGENCIES VISITED

The agencies and personnel listed below were visited in the course of this study. In addition to granting extensive personal interviews, in some cases they provided copies of warranty agreements, reports, and other data.

AIRLINES

Company	Location	Person and Function*
Piedmont Airlines	Winston-Salem, N.C.	A. Lenderman (1)
National Airlines	Miami, Fla.	T. Lauck (3) C. Sullivan (3)
Eastern Airlines	Miami, Fla.	H. Harrison (1) L. Worsham (3)
United Airlines	San Francisco, Cal.	T. Ellison (1) L. Olson (1) C. Smith (2) H. Swinehart (2)
American Airlines	Tulsa, Oklahoma	G. Campbell (1) C. Keaney (6) W. Flottman (2)
Pan American Airlines	New York, N.Y.	G. Hiller (3) W. King (1)

VENDORS

Company	Location	Person and Function*
Bendix Avionics	Ft. Lauderdale, Fla.	R. Winston (4) C. Cargil (4) H. Nevill (4)
Lear Siegler Astronautics	Santa Monica, Cal.	G. Fitzgerald (5) J. Tommasino (6)

*(1) = Engineering/Maintenance
(2) = Purchasing
(3) = Warranty Administration
(4) = Sales/Marketing
(5) = Customer Service/Support
(6) = Contracts

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VENDORS

Company	Location	Person and Function*
Litton Systems	Woodland Hills, Cal.	R. Bonswor (4) R. Snyder (6)
King Radio	Olathe, Kansas	C. Bennett (5) J. Rosenlieb (4)
Collins Radio	Cedar Rapids, Iowa	K. Engholm (5) J. Gooden (4)
Lear Siegler Instruments	Grand Rapids, Mich.	J. Harty (5) G. Ewalt (4)

Agency	Location	Persons
NAVAIR (Instruments)	Jefferson Plaza, Va.	E. Hall
ASD (ARC - XXX)	WPAFB, Ohio	Col. M[illegible]trie
ASD (Nav. & Guid.)	WPAFB, Ohio	R. Ittleson R. Perdzock
AFLC (Procurement)	WPAFB, Ohio	Col. H. Perry
Air Staff (DoD)	Pentagon	Lt. Col. B. Weiss Lt. Col. J. Clune G. Jett
ASO (Engineering)	Philadelphia, Pa.	O. Markowitz
AFSC (Procurement)	Andrews AFB	Col. Sparks K. Spates
ESD (Program Office)	L.G. Hanscom Field	M. Ratynski G. Walker Capt. W. Rustemeyer

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REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER: RADC-TR-73-249
2. GOVT ACCESSION NO.:
3. RECIPIENT'S CATALOG NUMBER:
4. TITLE (and Subtitle): THE USE OF WARRANTIES FOR DEFENSE AVIONICS PROCUREMENT
5. TYPE OF REPORT & PERIOD COVERED: Final Technical Report, 5 March 73 - 14 June 73
6. PERFORMING ORG. REPORT NUMBER: 0637-02-1-1243
7. AUTHOR(s): Harold S. Balaban, Bernard L. Retterer
8. CONTRACT OR GRANT NUMBER(s): F30602-73-C-0207
9. PERFORMING ORGANIZATION NAME AND ADDRESS: ARINC Research Corporation, 2551 Riva Road, Annapolis MD 21401
10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 23600201
11. CONTROLLING OFFICE NAME AND ADDRESS: Defense Advanced Research Projects Agency, 1400 Wilson Blvd., Arlington VA 22209
12. REPORT DATE: June 1973
13. NUMBER OF PAGES:
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): Rome Air Development Center (RBRS), Griffiss Air Force Base, New York 13441
15. SECURITY CLASS (of this report): Unclassified
15a. DECLASSIFICATION DOWNGRADING SCHEDULE:
16. DISTRIBUTION STATEMENT (of this Report): Approved for public release; distribution unlimited.
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report): Same
18. SUPPLEMENTARY NOTES:
    Monitored by:
    Anthony J. Feduccia
    RADC, GAFB, NY 13441
    315 330-2540
19. KEY WORDS (Continue on reverse side if necessary and identify by block number):
    Warranty
    Reliability
    Guarantee
    Airborne Electronics
    Life-Cycle Cost
20. ABSTRACT (Continue on reverse side if necessary and identify by block number):

The objective of this study was to investigate the potential benefit of using warranty agreements as part of military avionics procurements. The approach taken was to interview airline and military activities and their suppliers who in the past have made use of warranties. The survey was accomplished and included six airlines, six vendors and seven military agencies. In addition to these interviews, a literature search was performed relative to past studies of warranty usage. A life-cycle cost model was formulated which permits cost

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comparisons to be made between warranty and no-warranty procurements. The model permits the computation of the optimum warranty time period and break-even or indifference cost to identify the minimum added cost which may be spent on warranty coverage. A number of conclusions and recommendations stemming from the study are made concerning the application and administration of warranties for avionic systems. Also a Phase II program was outlined defining a program to further develop alternative warranty plans, analysis procedures and a validation program.